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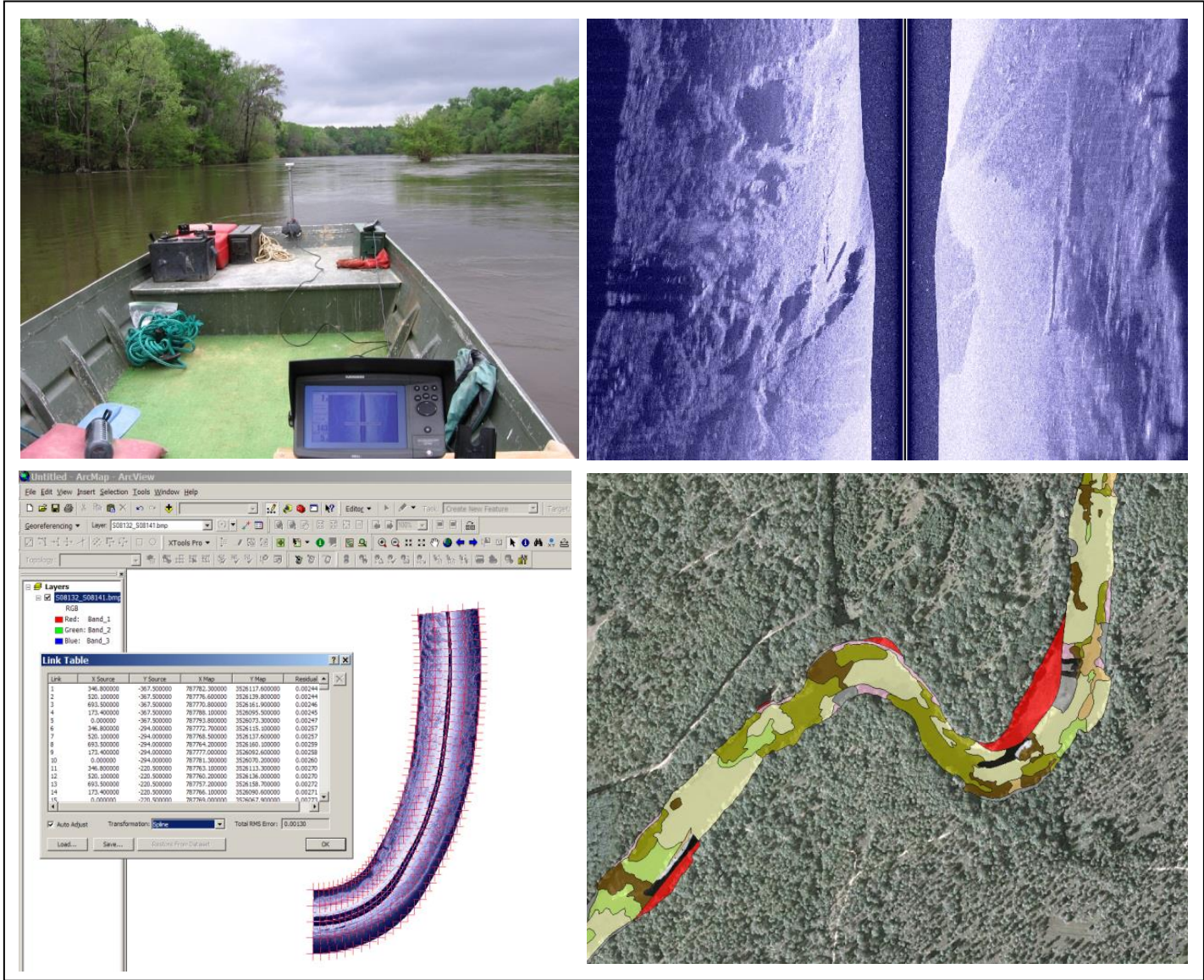


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# An Illustrated Guide to Low-cost, Side Scan Sonar Habitat Mapping

by Adam J. Kaeser and Thom L. Litts  
Version 1.0 April 2013





# Preface

This guidebook represents the fully annotated version of a Continuing Education workshop prepared by Kaeser and Litts to train natural resource professionals interested in low-cost, side scan sonar mapping in navigable, aquatic systems. This workshop was first presented at an early 2008 meeting of the Southern Division of the American Fisheries Society in Wheeling, West Virginia, and has since been presented over a dozen times nationwide. Over this time the program has been substantially revised and improved. In the spirit of widespread access and outreach, we have prepared this guidebook to provide the information electronically to anyone interested in the pursuit of sonar habitat mapping.

The program is divided into several sessions that successively build upon one another with the ultimate goal of establishing a foundation for the method we call low-cost sonar habitat mapping. This foundation includes understanding, planning, and executing a sonar mapping survey, geoprocessing the collected sonar data, preparing classified habitat layers by visual interpretation of transformed sonar imagery, evaluating elements of map accuracy, and exploring applications. The live workshop incorporates a virtual demonstration of the geoprocessing approach and tools developed by Litts for creation of the sonar image map layers. The technical details of this process are tackled with the aid of the Sonar Imagery Geoprocessing Workbook and a demonstration data set that accompanies this Guide.

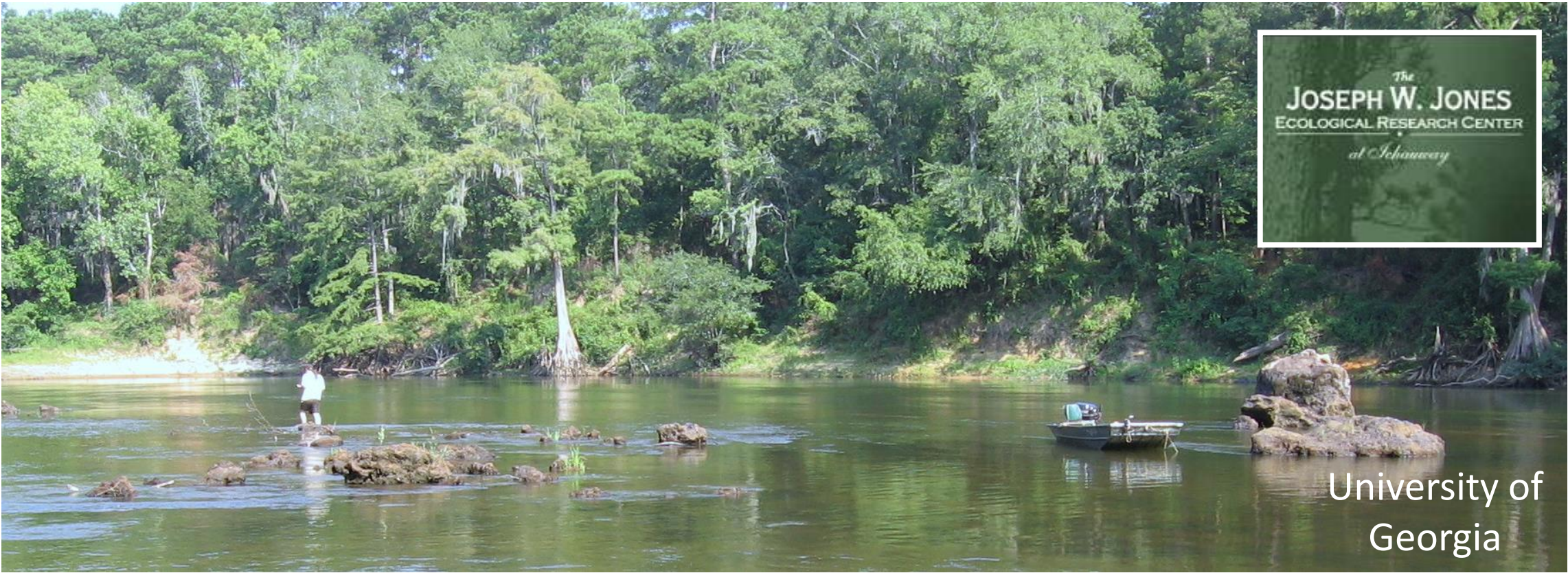
# Sonar Mapping Workshop



*TXAFS- San Marcos, TX, February 2011*



We gratefully acknowledge support for this work provided by:



University of Georgia

SDAFS Reservoir Committee





## Map envy

Walk through any university geography department and it's hard not to be drawn to the endless variety of maps that adorn the halls. Modern remote sensing has revealed our natural and man-made landscapes with incredible detail and accuracy. Access to these geographic databases has, in turn, supported the rapid growth of landscape ecology in applied and theoretical directions. These advances have truly benefitted the field of aquatic ecology as well, as these tools and data allow us to examine and study the relationships between land use and aquatic organisms at larger spatial scales. A closer look, however, reveals that an important piece of this landscape matrix still remains largely hidden from view...

# Landscape Ecology has flourished...

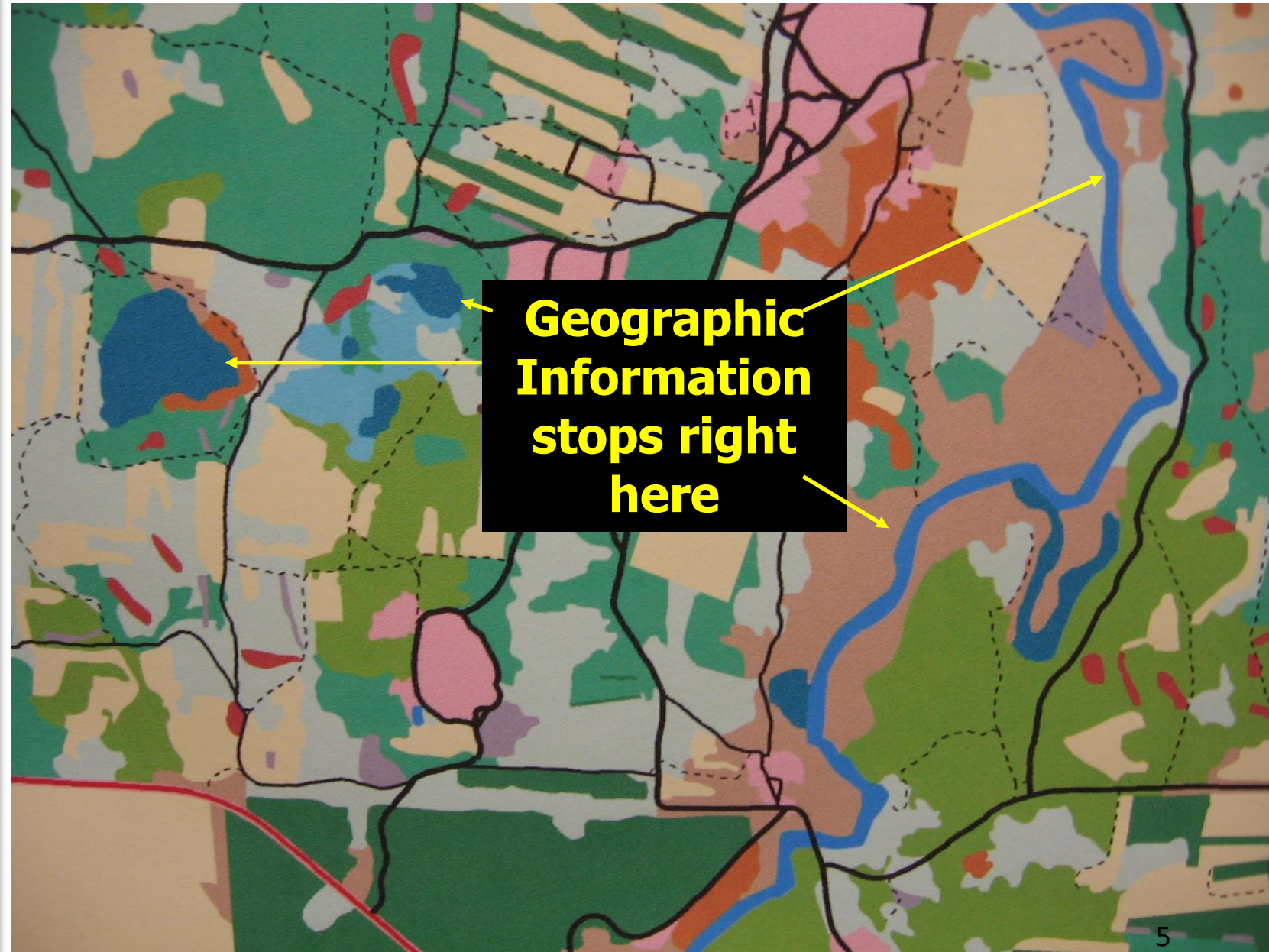




## Beyond the water's edge

The aquatic systems of this landscape are neatly represented by blue ribbons and irregular polygons, yet we can glean little from this map of the habitat beneath the water's surface. To conduct meaningful studies of submerged aquatic habitat, to better understand the patterns of distribution and abundance of aquatic organisms that rely on this habitat, and to develop robust, predictive models of species distributions at the landscape level, we need a set of tools and techniques that reveal and characterize in detail the underwater landscape.

## Riverscape Ecology has lagged behind





## Field sampling

Traditional approaches to gathering in-stream habitat data are often labor-intensive, and involve spot or transect based sampling. This approach is greatly facilitated by low, clear water conditions, yet remains difficult to execute over large spatial extents (i.e., the landscape scale). In some cases, gaps between point samples are interpolated to provide continuous-coverage habitat maps.

## Traditional Approaches

- **labor intensive**
- **wadeable, non-turbid streams**
- **small spatial extents**





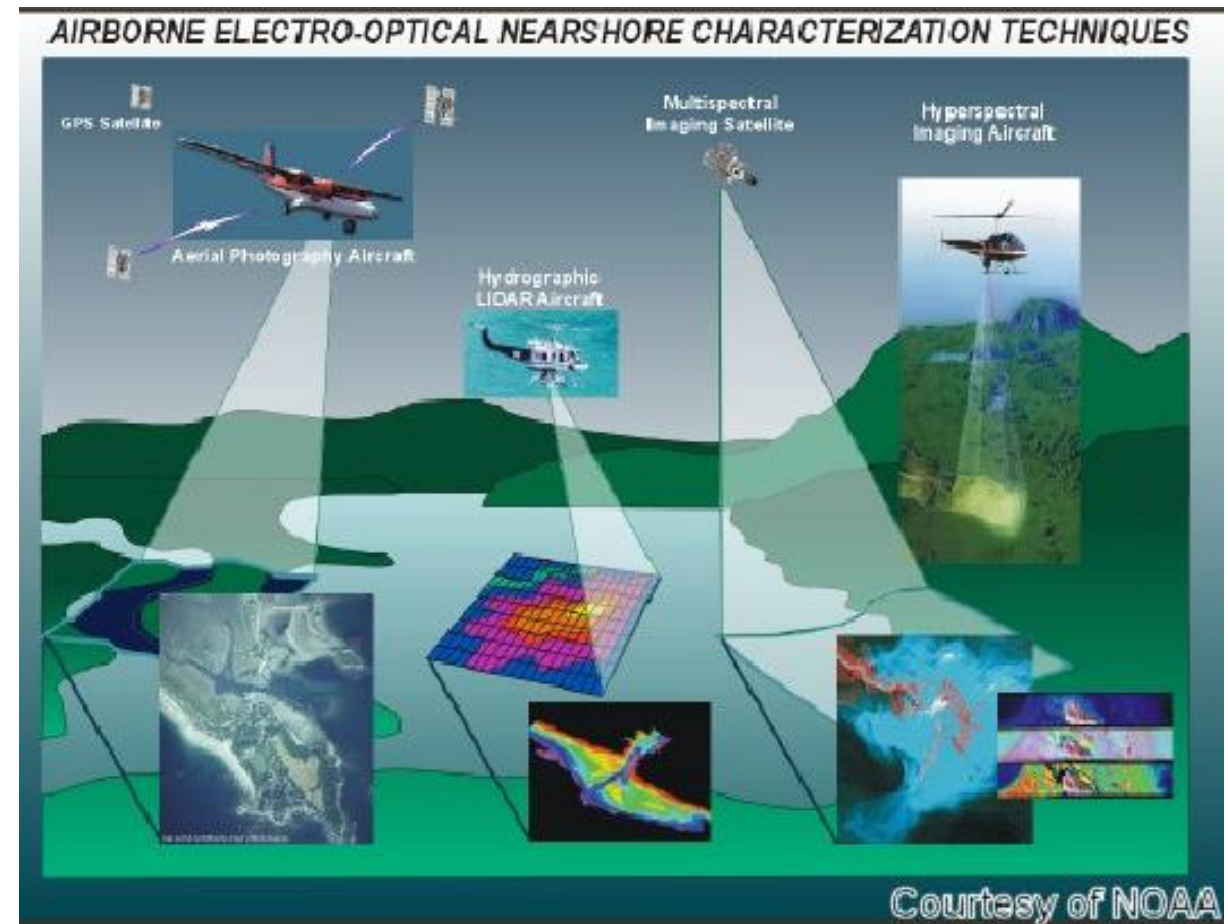
## Alternatives

A variety of remote sensing techniques have been demonstrated, and applied to the acquisition of landscape level data for underwater habitat features. Some of these approaches include air photography, laser scanning, and infrared imaging. A literature search will reveal a variety of contemporary articles describing the application of these sophisticated technologies in studies of aquatic systems.

# Remote Sensing Approaches

## Examples

- Optical Aerial Imaging
- LiDAR (laser scanning) (DEMs)
- RADAR (discharge)
- Thermal mapping (infrared)



# Alternatives

These hi-tech approaches are, however, challenged by one or more financial, logistical, or physical limitations; we suspect these factors will continue to preclude or inhibit the widespread adoption of these methods for mapping aquatic habitat. As illustrated here, many approaches demand the airborne deployment of a sensor system- a non-trivial expense in the budget of any mapping project. The systems are also quite expensive, and require technical expertise and specialized software for operation and processing of acquired data.

Even if associated expenses and technical expertise are covered, a variety of physical limitations such as depth, turbidity, and overhead canopy cover prevent the acquisition of data using airborne systems from many navigable waterways, especially those common to the Southeast Coastal Plain where we conduct our work.

# Remote Sensing Approaches

## Limitations

### Financial-Logistical

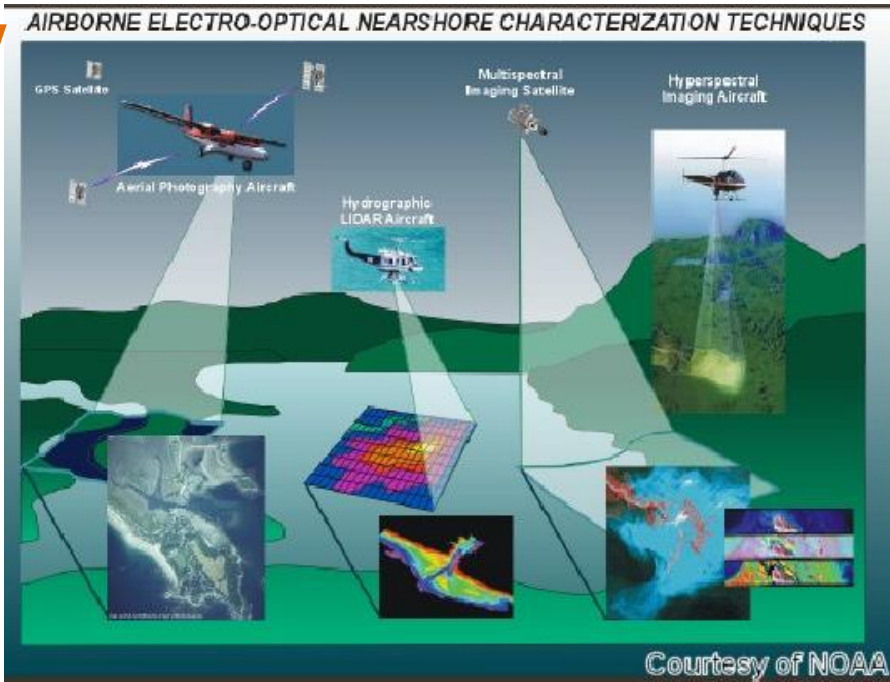
Sensor systems- \$\$\$

Airborne surveys- \$\$\$

Technical specialists,  
software required- \$\$\$

### Physical

Depth, Turbidity, Overhead (Canopy) Cover

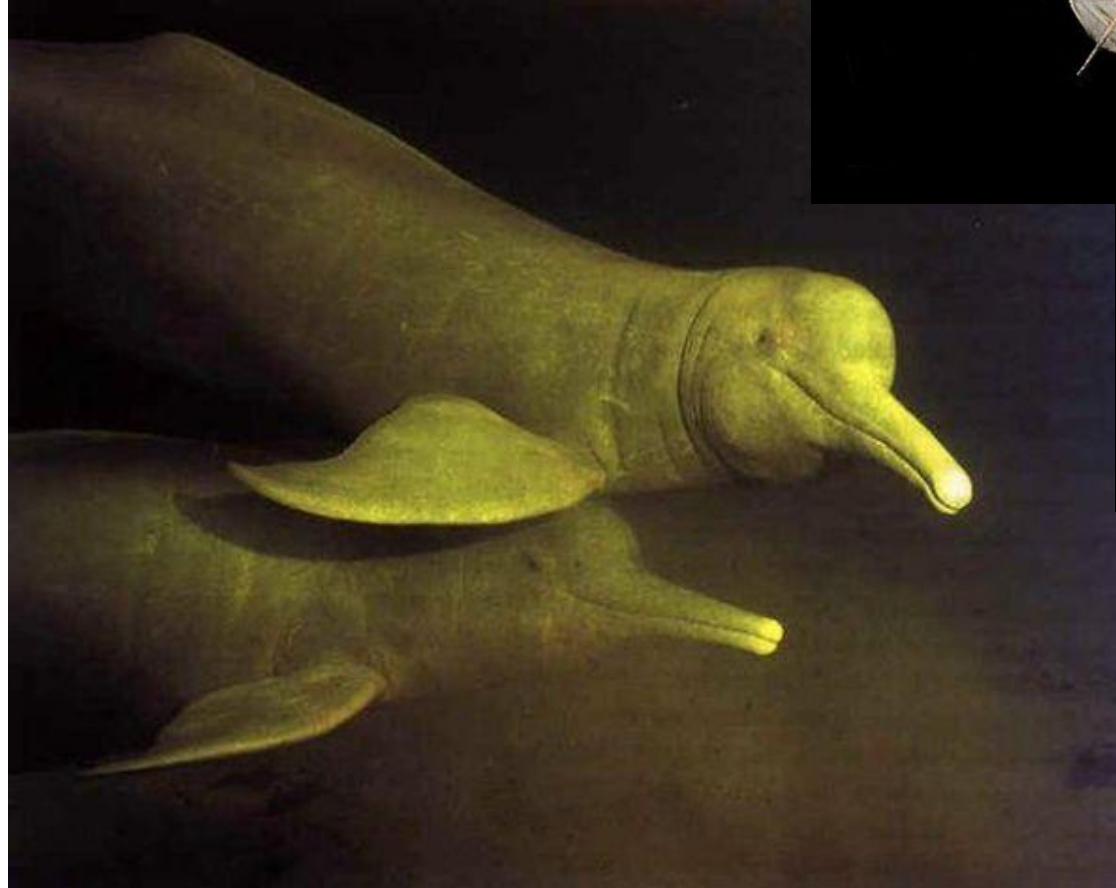




## “Sound” imaging in nature

Long ago nature invented a means for visualizing terrestrial and aquatic environments using high frequency sound waves. SONAR (sound and navigation ranging) overcomes the visual limitations imposed by nightfall or turbidity.

# Nature Invented SONAR





## Sight by sound

The remarkable use of sonar by humans, particularly members of the blind community, is aptly demonstrated by individuals such as David Kish (pictured right), the director of World Access for the Blind. This organization provides training on the use of sonar, by way of oral clicking sounds, to navigate complex landscapes, even while mountain biking.

# Humans use SONAR!





## Side scan sonar (SSS)

The development of sonar systems for underwater exploration began in the early 1900s. During the 1960s a new system emerged that was capable of producing 2-dimensional images of cross-sectional swaths of the benthic environment. Side scan or side imaging sonar has since been commonly used to chart navigational channels, map offshore marine environments, and search large areas for sunken vessels. Side scan sonar was used to locate the *Titanic* in 1985 and many other shipwrecks.

Side scan sonar is not limited by depth and turbidity. In deep water environments the transducer is typically attached to a towfish that is tethered by an adjustable cable and towed at depth (i.e. flown) behind a moving vessel (the towfish is identified in the adjacent image). Reasons for deploying the transducer in this fashion will be discussed later in the program.

Despite overcoming several key limitations, conventional side scan systems are expensive, their operation requires technical expertise, and data must be processed using specialized software. These factors have presumably limited the application of side scan sonar in inland freshwater systems.

# Humans adopt SONAR for underwater exploration

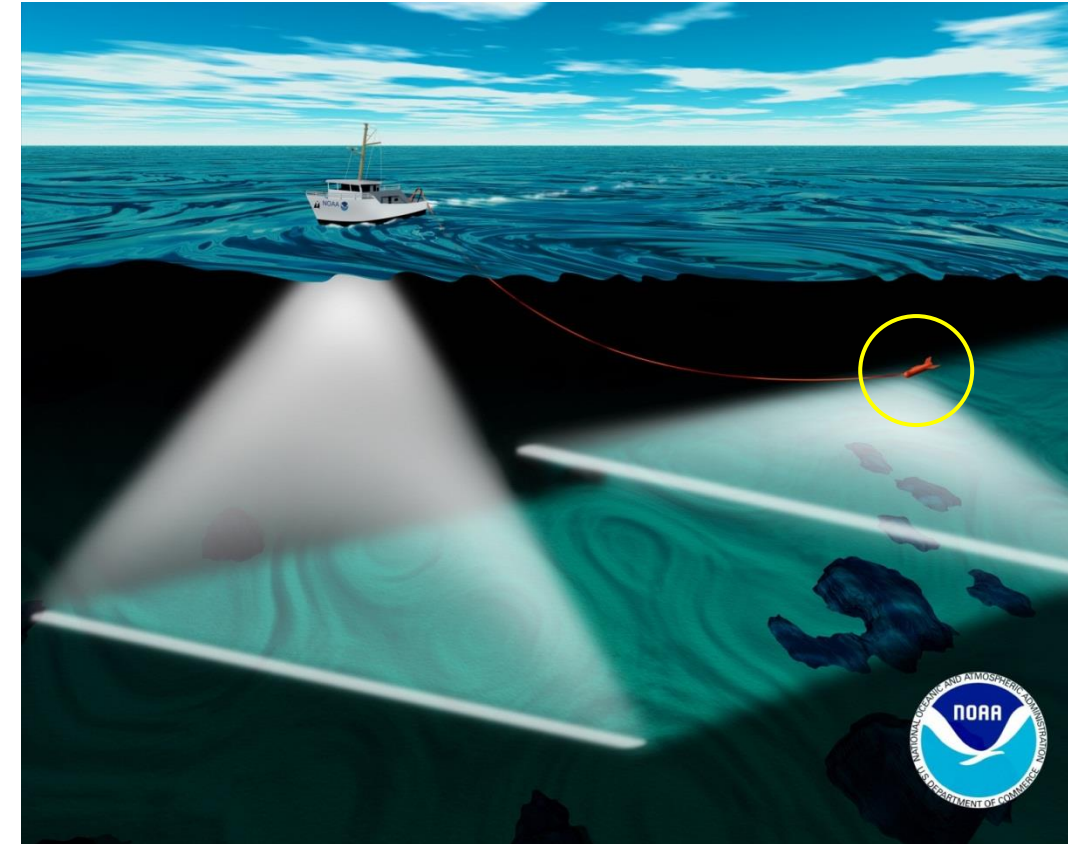
*circa 1900*

## *Side Scan Sonar* (1963)

Conventional oceanographic uses include search and recovery (e.g., shipwrecks) seafloor and shipping channel mapping in deep water

**Not Limited by:**  
Depth, Turbidity,  
Overhead Cover

**BUT...** \$\$\$





## Recreational SSS

In 2005 the Humminbird® Company, based in Eufaula Alabama, introduced the first recreational grade side scan sonar system, a product that has dramatically changed the sonar landscape, to say the least. The Humminbird® Side Imaging (HSI) system offers two primary advantages over conventional systems- high quality imagery at a very low price, and a small adjustable transducer that can be deployed on a small watercraft. The affordability of the hardware is a major reason why we have dubbed this enterprise “low-cost” sonar habitat mapping.

### 2 Major Advances-

- 1) **High quality imagery at low price**
- 2) **Small adjustable transducer**

The cost for a new Side Imaging system ranges from \$2000-2700. Humminbird® primarily markets the system to professional and serious amateur fishermen, although several other user groups, like divers, have also embraced the product.

*\*Kaeser and Litts are NOT representatives of the Humminbird® Company, and have not received any funding or support from Humminbird® for their work.*

# Humminbird® Side Imaging System

***Introduced 2005***

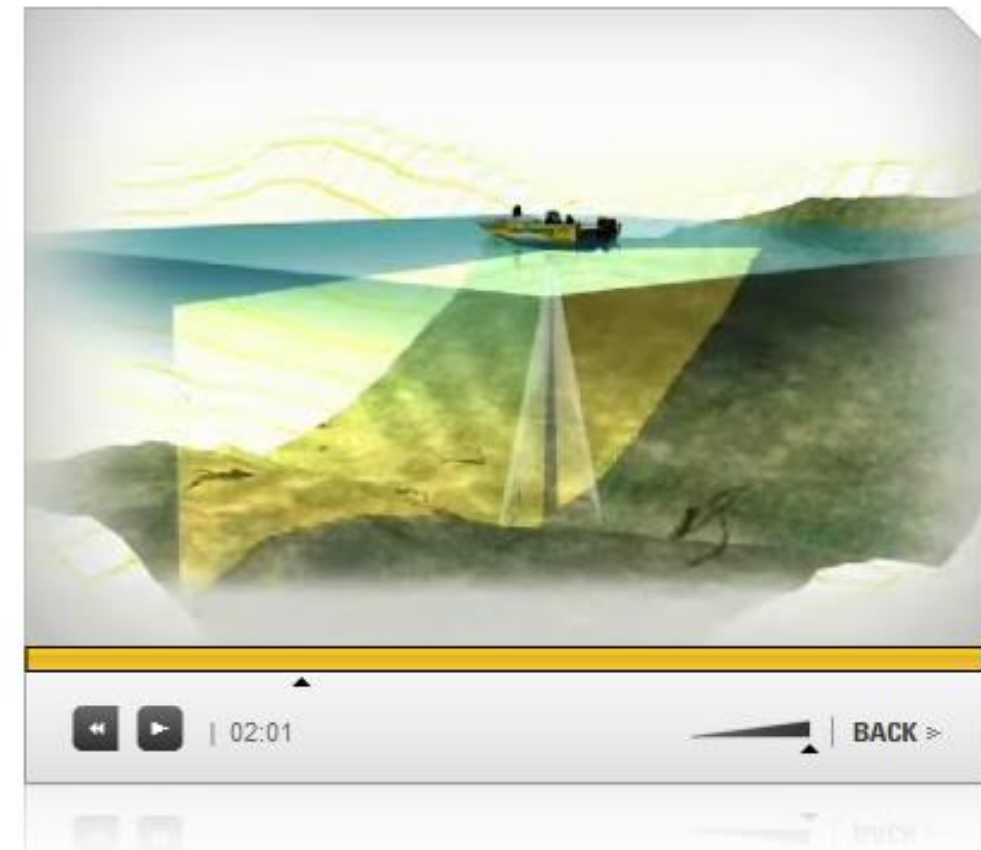


UNDERSTANDING SIDE IMAGING  
WHAT SIDE IMAGING SHOWS YOU  
WHAT THE PROS ARE SAYING  
SIDE IMAGING PRODUCTS  
SEE SIDE IMAGING IN ACTION



**~\$2,000-\$2,700**

### ✧ UNDERSTANDING SIDE IMAGING





# Recreational SSS

For several years, the Humminbird® Side Imaging system was the only recreational grade side scan system, but in 2009 Lowrance released their version of SSS called StructureScan. This is a modular system, and the StructureScan component must be integrated with other Lowrance sonar modules.

Since 2006 we have worked exclusively with the Humminbird® Side Imaging system, and cannot offer much advice on the operation of the Lowrance StructureScan. We have fielded several inquiries regarding whether our geoprocessing methodology can be adapted for StructureScan imagery. At the time of writing this remains an untested possibility, although in theory the methodology should be transferable. For an up-to-date synopsis of this issue, please contact the authors.

# Lowrance equivalent- StructureScan

*Introduced Summer 2009*

LOWRANCE

PRODUCTS   SUPPORT   DOWNLOADS   COMMUNITY   DEALER LOCATOR   ABOUT

Search

Marine

HDS® High-Def System

Mark™ & Elite™ Series

Compact Fishfinders

Paddlesports

Ice Fishing

SonicHub™ Marine Audio

StructureScan™

System

Features

Screenshots

Testimonials

Ethernet Networking

NMEA 2000® Networking

Digital Gauges

Broadband 3G™ Radar

HD Digital Radar


DSC VHF Marine Radios

Outdoor GPS

Mapping

Legacy Products

Accessories




1

2

3

13.4%

Lowrance StructureScan™ Overview - Better Imaging



Description	Specifications	Downloads	Accessories
Incredible Lowrance StructureScan™ Sonar Imaging Option for HDS®.			
Sees More. Shows More. Does Much More.			



## The early days

We first learned of the Humminbird® Side Imaging system through our involvement in an unusual, 2-year program established to permit the salvage of pre-cut, submerged timber (a.k.a. deadhead logs) in rivers of South Georgia. Adam was responsible for coordinating the program, with Thom providing GIS expertise and support. Adam was informed of the HSI system while interviewing loggers who were participating in the state of Florida logging program. Several loggers had adopted the new technology in their hunt for logs. Traditional methods to locate logs usually involved diving in murky, gator-loving rivers and groping around, a slow and treacherous process. Side scan sonar was proving to be a fast and efficient alternative, worthy of investment.

\*Deadhead logs were rafted or floated down many Coastal Plain rivers of the southeastern United States around the turn of the 20<sup>th</sup> century, during an era when most of the old-growth, longleaf pine and cypress forests were felled. Many dense, resin-rich timbers sank during transport, and remain preserved underwater from decay. Their economic value today is extremely high due to the exceptional wood quality and rarity of the resource. Their ecological value, however, remains entirely unassessed by science, although their massive size, stability, and longevity in aquatic systems suggests exceptionally high natural value as well.

## The Georgia Deadhead Logging Program

**Suwannee River, FL**

## Genesis



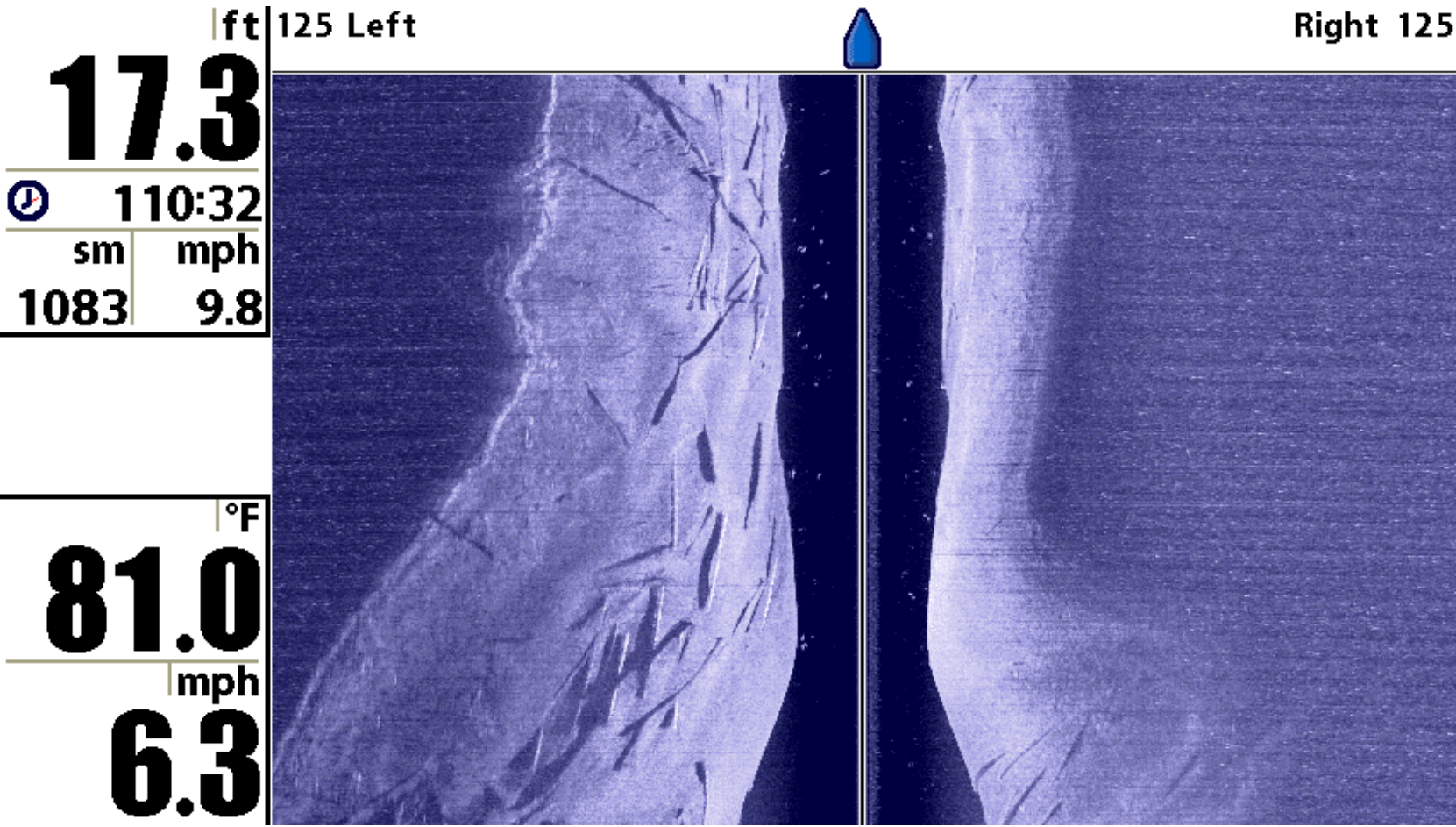


# Hunting deadheads

Side scan sonar permitted loggers to quickly survey long reaches of river in search of deadheads. The adjacent raw sonar image was captured in a slough of a large, Coastal Plain river. Along the left side of the boat, a nice cache of deadhead logs are seen resting on the sandy bottom. The long, straight, and uniformly cylindrical shape of these objects are tell-tale characteristics of deadhead logs. In some cases, only the sonar shadow being cast by the log is visible. Several logs appear to be partially embedded in sediment.

\*A log cache represents real value to a logging crew in terms of focusing salvage efforts. Given that a each deadhead log might fetch between \$200-400 when sold to a mill, this cache of logs would be welcome discovery.

# Deadhead Logs





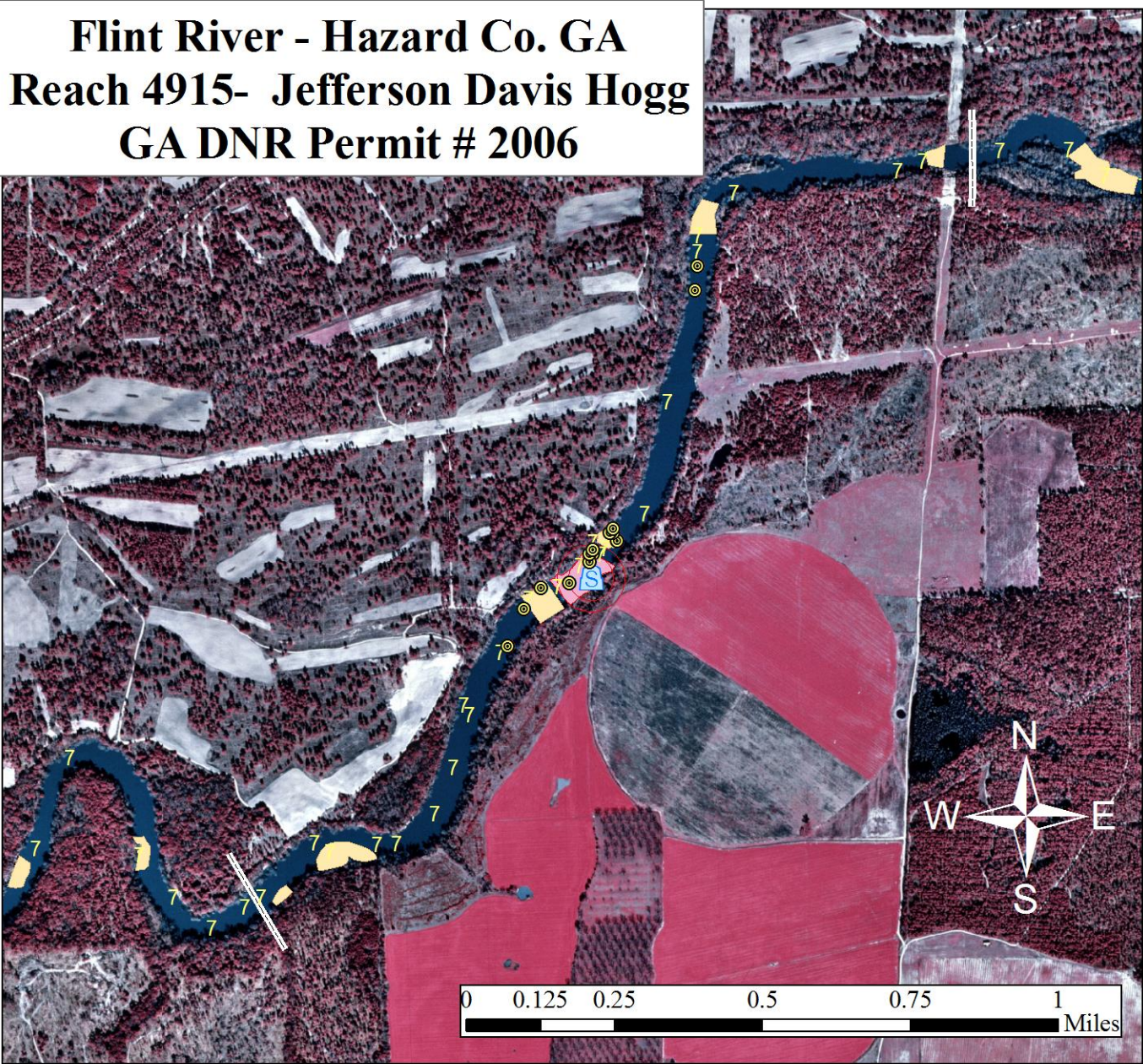
# SSS as a management tool

To better manage the logging program and monitor logger activities it was clear that Georgia DNR needed to acquire an HSI system. Moreover, little was known of the distribution and quantity of deadhead logs in Georgia rivers. This information was deemed vital to the development of reach-specific logging permits. In the Flint River, for example, several cold-water springs served as important summer refuges for Gulf striped bass, a species of high conservation concern. The policy on deadhead logging banned the removal of deadhead logs from the vicinity of these springs to limit disturbance to resident stripers. We used the HSI system to survey the length of the lower Flint River and mark the location of logs and log caches by capturing screen snapshots whenever logs were observed on the display screen (these locations are represented by the yellow "humbirdpts" on the map). This spatial information was overlaid in a GIS with spring locations, and buffers were added to define areas of restricted logging activity.

\*In the end the state of Georgia never issued a permit to legally salvage deadhead logs from any river.

You may also note that interpretation of sonar imagery on-the-fly during these early field surveys was used to crudely define the extent of shoal (i.e. shallow rocky boulder) areas in the river (beige polygons). We would later refine this data layer by mapping shoals directly from rectified sonar imagery captured during a second, full-river survey.

# Demonstration Permit Map



Legend

	humbirdpts
	sunken log
	Embedded log
	Boat Ramp
	Cold Water Spring
	Fed Mussels Site
	Dock
	BulkHead
	Deck
	Logging Prohibited
	Logging Permitted
	Fishing Access
	Residence
	Public Use
	boatRamps
	Restricted Area
	Reach Boundary
	Shoal

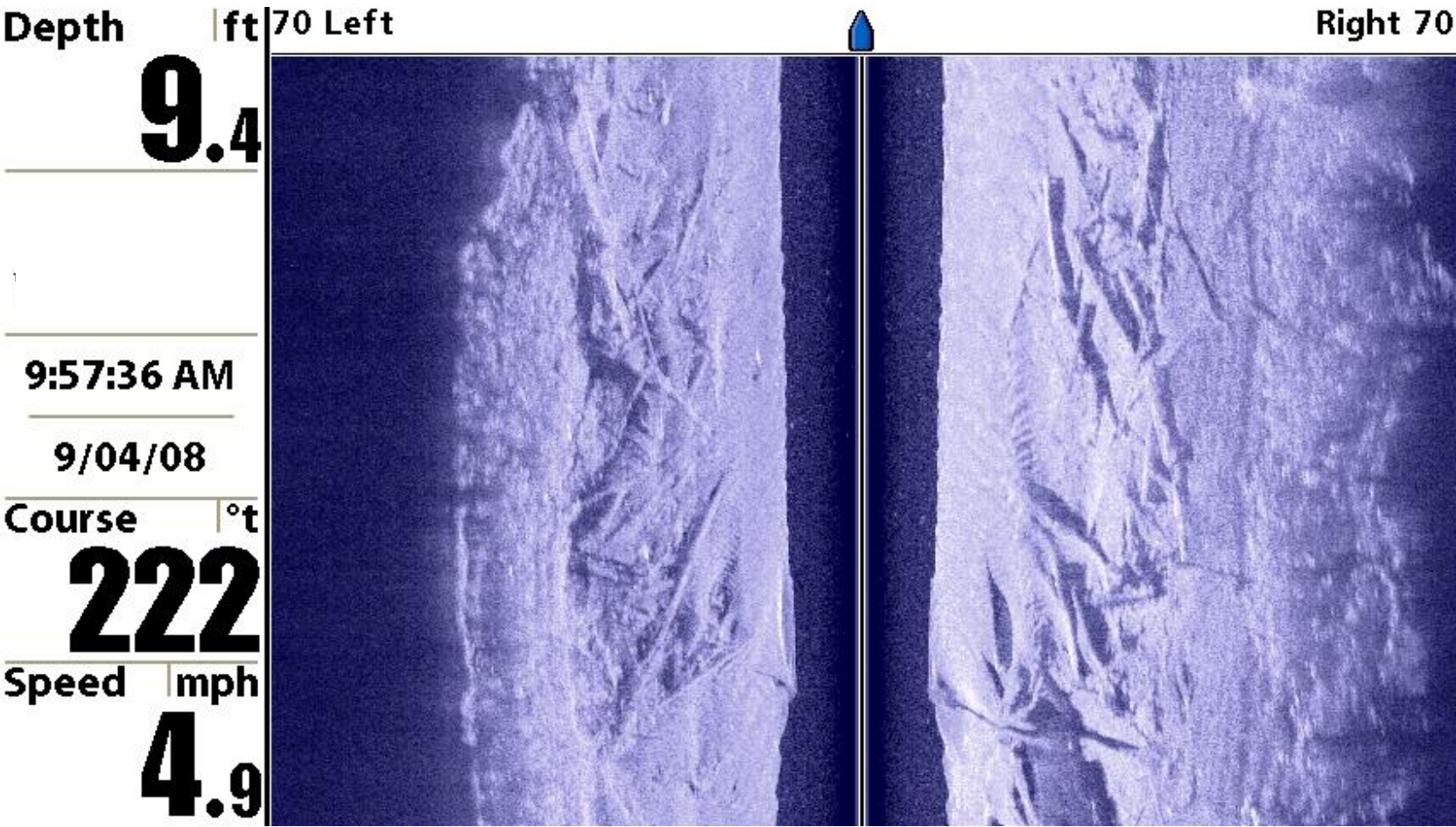


# Revelations

During our early work a variety of other objects and features appeared on the sonar screen. Although it wasn't always obvious at first what we were looking at, sonar provided a window through the muddy, Georgia rivers, revealing an otherwise mysterious world beneath the surface. One of our students described the experience of scanning as watching "The Riverchannel" on TV- it can certainly be addictive!

In the adjacent raw sonar image a collection of large woody debris appears to the left and right of the boat path, resting on a sandy creek bed. At least a few of these pieces also look like potential deadhead logs. You can, perhaps, imagine counting the number of pieces of wood in this image, or instead, defining the extent of these aggregations and classifying wood density.

# Other Large Woody Material

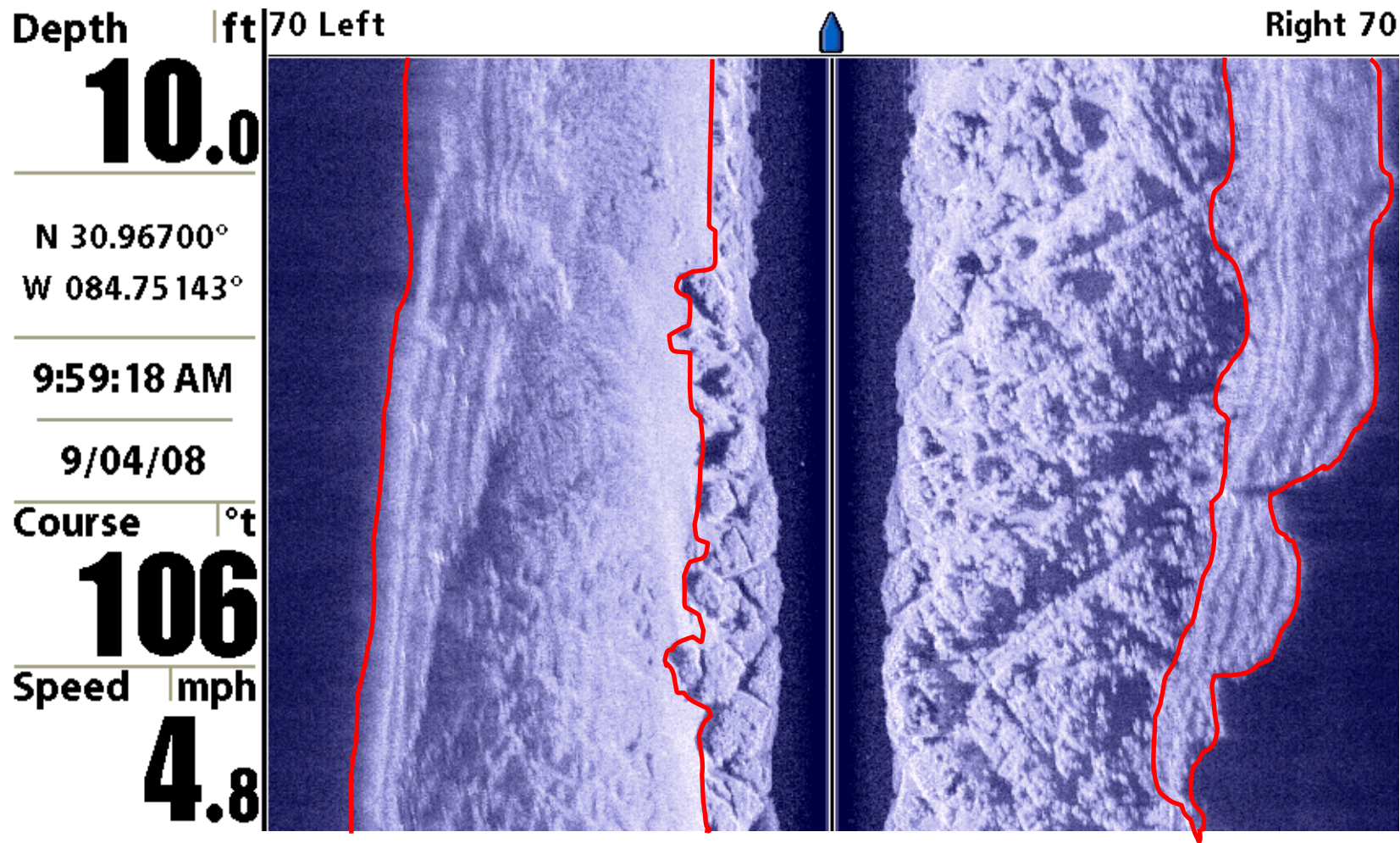




# Substrate patterns

Sonar also clearly revealed different substrate types- in the adjacent raw image a finely textured substrate appears to the far left (likely sand), and to the right an outcropping of limestone bedrock whose texture resembles that of cauliflower heads. Quite often, the boundaries between adjacent substrate types are abrupt and distinct, and we began to imagine drawing lines around these patches to map the mosaic of substrates in a stream reach.

# Sonar Image Features





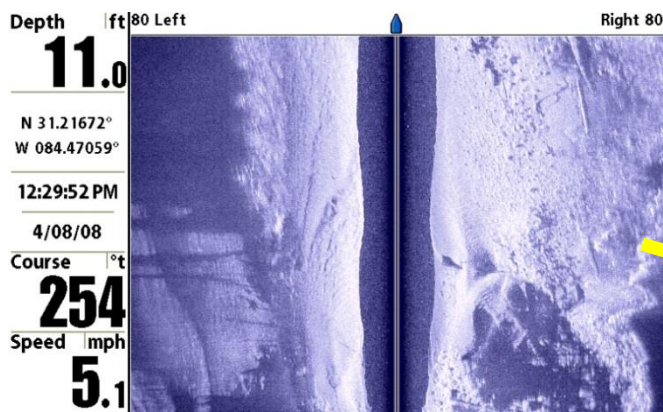
# How can we do this?

A major problem, however, exists with mapping observed features directly from a raw sonar image—raw images are dimensionally distorted. A raw sonar image does not properly portray the dimensional reality of the scene from which it was captured. For example, the rectangular image format of every raw sonar snapshot is identical, regardless of whether the image was captured in a straight reach of stream, or taken as the boat was negotiating a 90-degree bend. We cannot, therefore, simply drape a raw sonar image over its apparent position in the stream channel.

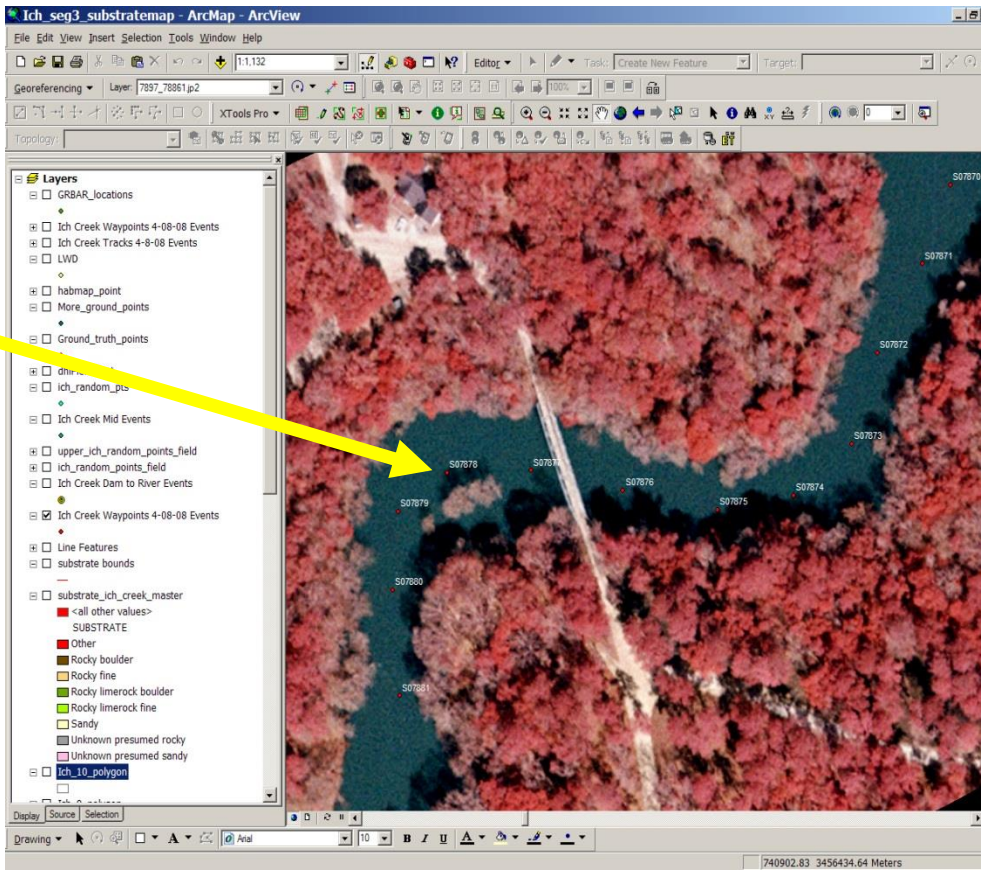
In order to develop spatially accurate maps of features observed in raw sonar imagery we must first correct the image dimensions using a process called image rectification or transformation. Correctly transformed imagery will properly fit the path taken during the sonar survey, thereby permitting the spatial delineation of visible objects and features.

Although a variety of software packages existed to process (i.e., rectify) sonar imagery from other systems, no software existed to process Humminbird® SI imagery when we began working with the system. Instead, we set out to develop our own method for acquiring and processing Humminbird® sonar imagery. The complete method would include not only a standardized means for collecting and geoprocessing sonar data, but also include the development and verification of classified maps of habitat features based on visual (i.e., manual) interpretation of sonar imagery.

# We need a METHOD that integrates low-cost sonar imagery and GIS to map underwater habitat!



\*Raw sonar images are dimensionally distorted, cannot simply be draped over channel





## Guiding principles

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The “Ideal Method”, we reasoned, would satisfy five key principles: the method would be affordable (i.e., low-cost), fast yet accurate, applicable in a variety of aquatic settings, the training would be available and reasonable, and the necessary software or tools would be those readily available to professionals involved in both research and management of aquatic systems (e.g., ArcGIS).

## The “Ideal Method” would be:

- **Affordable**
- **Fast, Efficient, and Accurate**
- **Applicable in diverse settings**
- **Training available and reasonable**
- **Software/tools accessible to researchers & managers**



## Our objectives

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The pursuit of the ideal method for mapping habitat with the Humminbird® SI system crystallized into what we refer to as the Sonar Mapping Initiative with six primary objectives, listed here. Work on this initiative began in 2006 and continues to this day.

# Sonar Mapping Initiative

## Objectives

- 1) Develop approaches for field sonar surveys**
- 2) Develop techniques for georeferencing and transformation (i.e., geoprocessing) of sonar imagery for use in a GIS**
- 3) Produce detailed maps of instream habitat features (e.g., banks, substrates, LWD, depth) via image interpretation and manual digitization**
- 4) Evaluate/validate the techniques and map accuracies through a series of mapping studies**
- 5) Develop and offer the tools, products, and training to interested professionals (workshops, internet)**
- 6) Continue to test and develop new applications of low-cost sonar habitat mapping**



## Training

A major objective of the initiative was to develop and provide the training needed for successful application of low-cost sonar habitat mapping. This workshop was specifically designed to help people get started with side scan sonar. Although we attempt to address several relevant aspects of sonar habitat mapping, this workshop alone is only part of a continuous learning process that will hopefully lead to successful mapping project outcomes. We feel it is very important for those involved to work with the equipment in their systems of interest, and seek opportunities to improve skills in all facets of the mapping process, from boat handling and data capture, to image interpretation and the development and testing of new field applications.

We fundamentally believe that freely available training materials are essential to the adoption and further development of this approach. This field will be expanded by those who find low-cost side scan sonar to be a useful, and perhaps indispensable tool to add to the natural resources toolkit.

## Workshop Objectives

- **Provide an overview of side scan sonar technology and imagery**
- **Quick-start guide to complete method we call low-cost sonar habitat mapping**
- **Demonstrate the potential for mapping submerged features of aquatic environments using sonar image maps**

## Program sessions

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The workshop is divided into four consecutive sessions. The first session provides an introduction to side scan sonar basics. Given the importance of image interpretation to low-cost sonar habitat mapping, the following session tackles the fundamentals of this topic with a variety of example images from the field.

# Workshop Format

## Session I- Part A

### Introduction to Side Scan Sonar

## Session I- Part B

### Image Interpretation



## Program sessions

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Mission planning considerations, and steps taken during the execution of a sonar survey are topics covered in the second full session of the workshop.

# Workshop Format

## **Session II- Part A**

### **Mission Planning**

## **Session II- Part B**

### **Mission Process**

## Program sessions

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The third workshop session is devoted to the technical topic of sonar data geoprocessing. This session, when presented to a live audience, includes a demonstration of the sonar processing tools developed by Thom Litts.

# Workshop Format

## Session III-

# Image Geoprocessing in ArcGIS



## A geoprocessing tangent

Before going any further in our discussion, let us point out an important distinction between the approach we have developed for geoprocessing Humminbird® SI system imagery, and the approach commonly taken when processing data from other side scan sonar systems.

# Sonar Mapping Initiative

## Objectives

- 1) Develop approaches for field sonar surveys
- 2) Develop techniques for georeferencing and transformation (i.e., geoprocessing) of sonar imagery for use in a GIS**
- 3) Produce detailed maps of instream habitat features (e.g., banks, substrates, LWD, depth) via image interpretation and manual digitization
- 4) Evaluate/validate the techniques and map accuracies through a series of mapping studies
- 5) Develop and offer the tools, products, and training to interested professionals (workshops, internet)
- 6) Continue to test and develop new applications of low-cost sonar habitat mapping

## Image capture

There are two ways to capture sonar imagery with the Humminbird® SI system. One approach is the screen snapshot- a single, still image of the control head display is created at the moment of image capture (much like a digital photograph). We have presented and discussed several of these screen snapshots (i.e., raw sonar images) in the program already. The second way to capture sonar imagery is to create a sonar recording. A sonar recording is a file that contains the streaming sonar data collected during the survey (like a video recording of the display screen). Sonar screen snapshots and recordings are both saved to an internal SD storage card, but it is **not** possible to capture sonar imagery in both formats simultaneously.

Back in 2006 we chose to pursue the development of a geoprocessing methodology that used screen snapshots, rather than sonar recordings, for several relevant reasons. Most importantly at this time a program to convert the proprietary .son Humminbird sonar file format into a common format such as .xft (extended triton format) did not exist. Unlike the .son format, the .xft format can be processed by several commercially available softwares. Several free conversion programs now exist to make this conversion possible.

We refer to our approach as the "Snapshot Approach". To our knowledge, this approach is fundamentally different from all other processing approaches that instead rely on the recorded, streaming sonar files. Relevant differences will later be discussed.

## 2 Ways to Capture Sonar Imagery

**Screen Snapshot**  
Digital image and Waypoint captured simultaneously, at a discrete point in time, as dictated by operator

**2) Sonar Recording**  
Continuous Sonar "video" and streaming GPS data captured, stored in .son file

**The "Snapshot Approach"**





## Program sessions

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Back to the workshop sessions- in the final session of the workshop we will discuss the preparation and evaluation of GIS-based maps containing several layers of habitat feature data.

# Workshop Format

## **Session IV- Part A**

### **Habitat Mapping**

## **Session IV- Part B**

### **LWD, Accuracy Assessment, Applications**

## Program Session I- Part A

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Let us begin with the Introduction to Side Scan Sonar.

# Session I- Part A

## Introduction to Side Scan Sonar



## What is unique about SSS

Side scan sonar is an active, remote sensing system; the equipment must be deployed by a user-operated watercraft. Side scan sonars produce two-dimensional imagery of the underwater landscape by transmitting and then receiving soundwaves reflected from submerged features.

Although the Humminbird® SI system can record the vertical depth between the transducer and the lake or river bottom (i.e., the transducer altitude), the system cannot provide depth across the sonar swath or cross-section. Cross-sectional depth records are generated by multibeam bathymetric or interferometric sonar systems which are generally more expensive than the HSI system. To some degree, and in certain circumstances, depth and topographic relief can be inferred through interpretation of sonar imagery by cues provided by sonar shadows and image tonal changes.

## Some Fundamentals

### What is Side Scan Sonar?

An actively deployed, remote sensing system capable of producing 2-D images of a 3-D underwater environment using sound transmitted through an aquatic medium

\*The HSI system is NOT a multibeam bathymetric or integrated “Interferometric” system, so does not provide depth info across swath

# SSS Components

A few hardware components comprise the side scan system we operate. The Humminbird® SI system control head is a small console that can be mounted aboard the survey vessel. This control head houses an internal SD card for storage and transfer of sonar image data and files. The HSI system includes a small, foot-like transducer. If the transducer is destroyed during a mishap, a replacement can be purchased at a modest cost. Although some of the HSI models are packaged with a GPS receiver, we recommend the substitution of a hand-held unit like the Garmin GPSmap series device for purposes of easily recording and transferring a breadcrumb, track file that includes a depth observation at every track point. The last piece of hardware included in our set-up is a Seiko interval timer stopwatch. The stopwatch assists with the timing of sonar snapshot image capture during surveys, a process we will discuss in detail later.

# What Equipment is Involved?

## Control head

- Humminbird 900 or 1100 series
- SD Card for data storage



## Transducer/Transmitter

- XHS-9-HDSI-180-T (1100 series; \$240 replacement cost)



## Global Positioning System (GPS)

- Garmin GPSmap 76, 76C, 76CSx (\$150-300)
- WAAS enabled (3-5m accuracy)



## Seiko S057 Interval Timer (\$85)





## SSS operation

Side scan sonars produce acoustic pulses (pings) that travel through the water column, strike objects or the bottom, and are reflected back to the transducer. The strength and timing of the returning pulses (i.e., the backscatter) are translated by the system into consecutive rows of shaded pixels that together create a flat image of the underwater environment. As an active, remote sensing system, the gear (vessel) must be moving across the surface in order to create an interpretable image. The process is similar to the scanning of a document. The vessel and sonar gear act as the light bar that travels over the surface of a document in a copy machine.

## How does SSS work?

- System produces an acoustic pulse (ping) that transmits perpendicular to the boat path through the water column as a very narrow beam
- The pulse strikes and reflects off features (insonification) and sonar energy returns to the transducer
- Travel time and amplitude (strength) of the returned pulse is processed and transformed by the control head into a row of shaded pixels representing a thin, cross-section of the swath (channel)
- Consecutive rows of pixels (strips of information) create a continuous image of the bottom that resembles a cryptic digital photograph
- The process of image creation is like scanning a document- the vessel (scanner) must move across the surface



\*\*Image Source: <http://www.starfishsonar.com/technology/sidescan-sonar.htm>

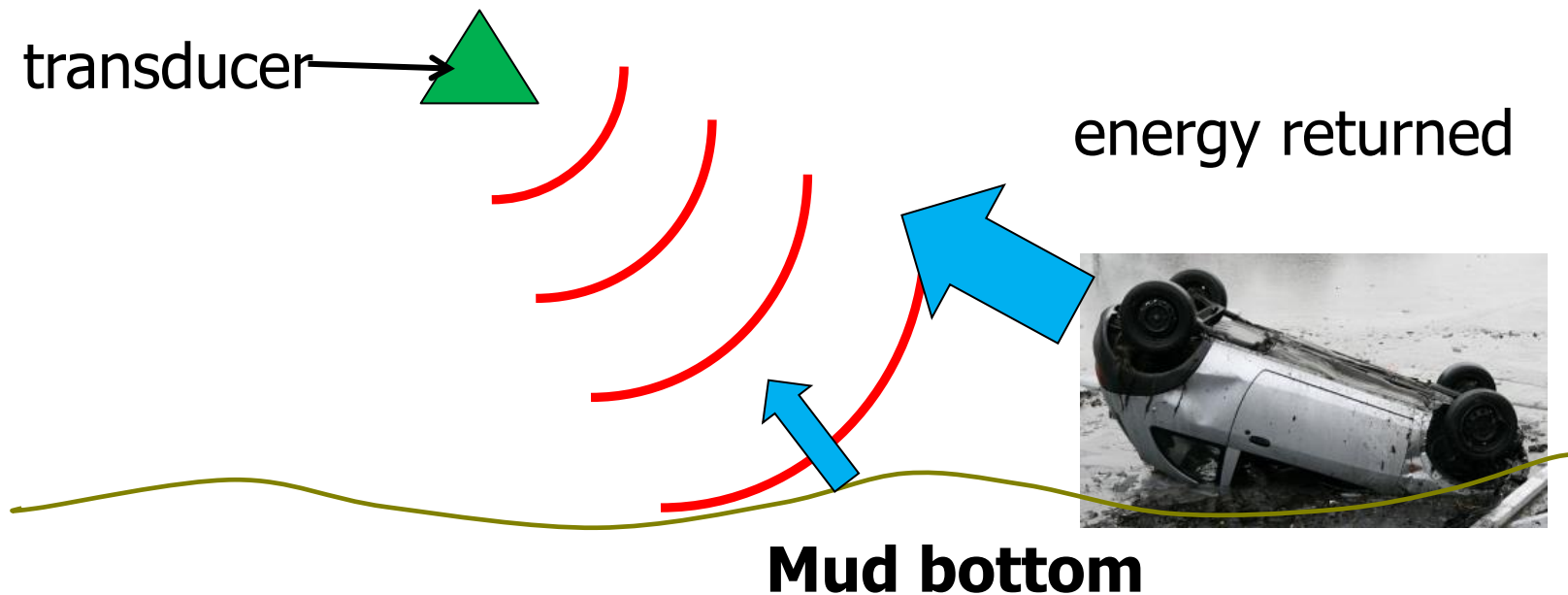
# Amplitude

The amplitude, or strength of the reflected acoustic pulse, plays a critical role in ability of side scan sonar to produce imagery that illustrates differences among features. Return signal amplitude is influenced by several factors, and it is important that we discuss these factors and their effects on sonar image production.

Signal amplitude can be affected by the density of the object or surface that reflects the signal. Dense, hard objects like rock boulders, concrete bridge abutments, or sunken vehicles reflect more sonar energy than soft surfaces like the muddy bottom of a lake cove.

# The Role of Amplitude

- Amplitude is the strength of acoustic signal reflected from the bottom or other submerged features
- Dense objects such as rocks or metal reflect more sonar energy, whereas soft objects (eg. mud, silt, organic debris, fish or human flesh) absorb energy and reflect weaker signals





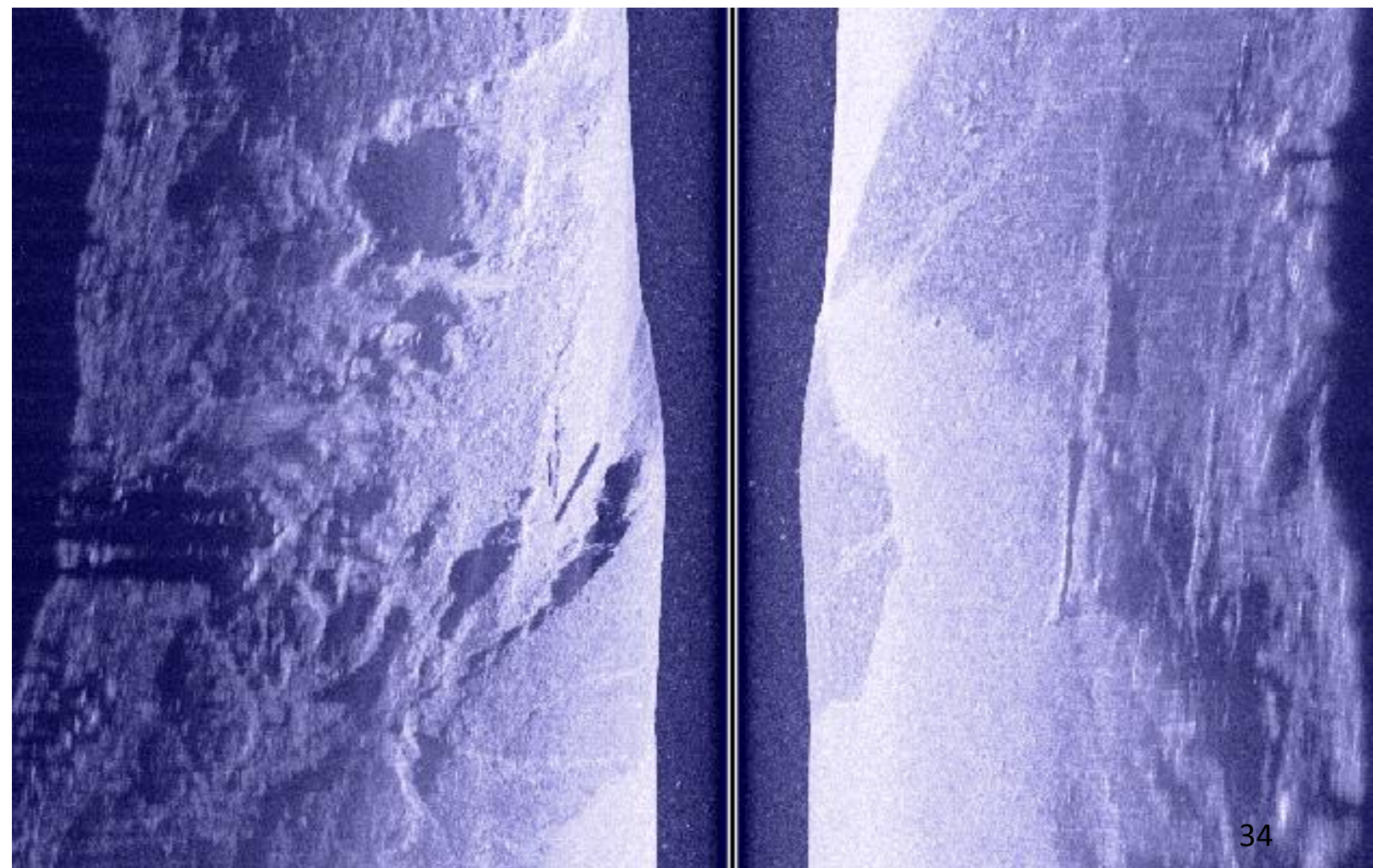
# Amplitude

The side scan system measures the amplitude of returning signal pulses and translates differences in amplitude into differences in pixel tone in the developing sonar image. Differences in pixel tone are readily apparent between the left and right hand sides of the adjacent image. On the left side, a darker pixel tone predominates, and on the right side the darker tone occupies only discrete portions of the image. Areas of lighter pixel tone also occupy part of the right side. These tonal differences are due to differences in substrate composition- the darker tone is representative of hard, reflective limestone bedrock, and the lighter, almost white tone is representative of sand in this river reach. Tonal characteristics within clusters can help to differentiate features on the basis of apparent image texture and shape.

\*Note what appears to be a perfectly outlined deadhead log resting on the bottom, left of center in this image.

# Amplitude

- The measured amplitude response allows features that differ in density to be discriminated on basis of pixel tone
- Tonal characteristics within clusters can help differentiate features on basis of apparent image texture and conformation (shape)

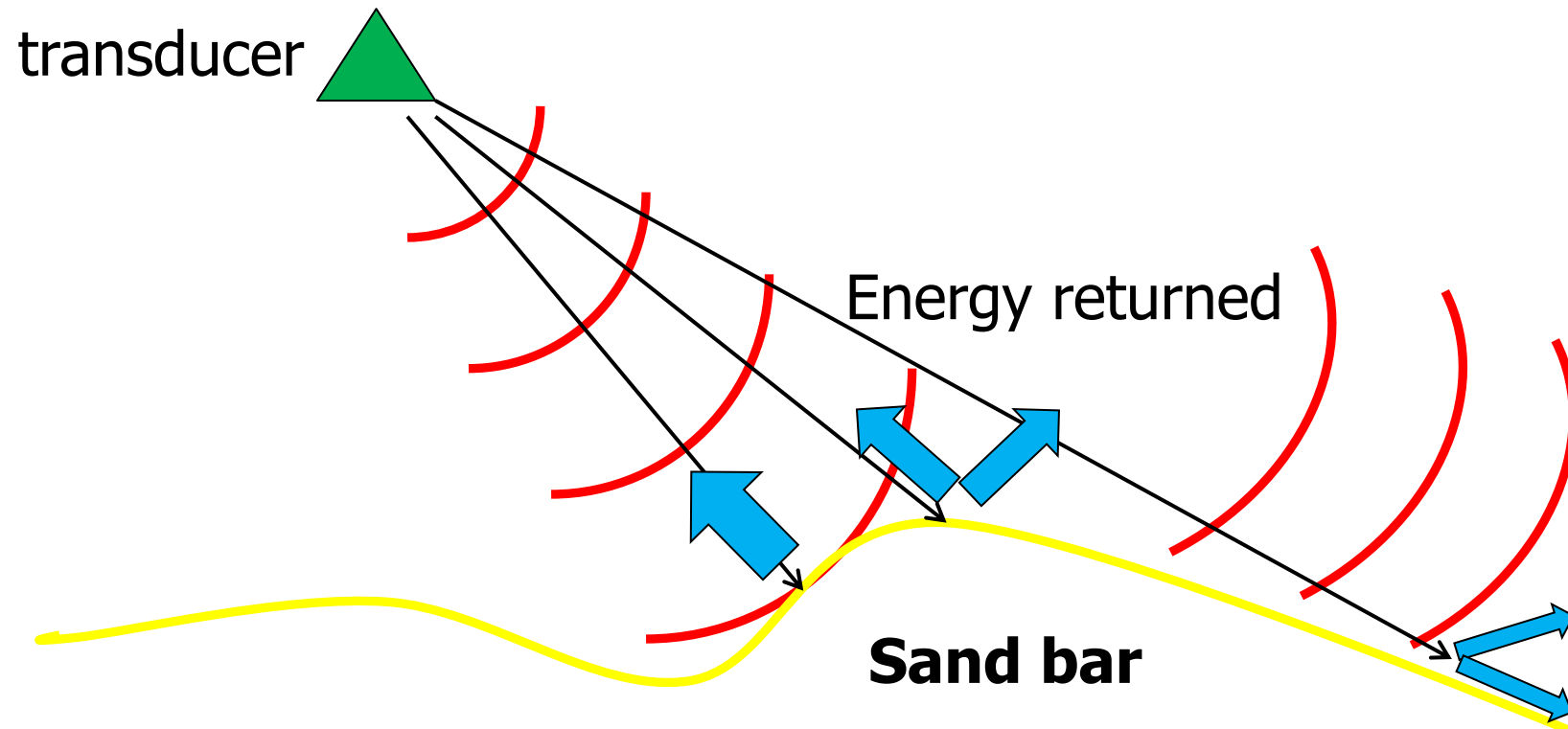


# Amplitude

Signal amplitude is also influenced by the angle at which the signal strikes an object or surface. This angle of incidence is also called the “grazing angle”. In the example provided here, we are scanning a stream whose bottom surface is entirely sand in composition, with sand bars providing some topographic relief. Although substrate composition is the same throughout, the leading edge of the sand bar (the edge facing the transducer) will reflect more sonar signal energy than the trailing, down-sloping edge of the sand bar. The backside of the sandbar reflects less sonar energy (i.e., lower signal amplitude) to the transducer, and we should expect to find tonal differences across the resulting sonar image.

# Amplitude

- Amplitude is also influenced by other factors, such as the angle of incidence or “grazing angle”





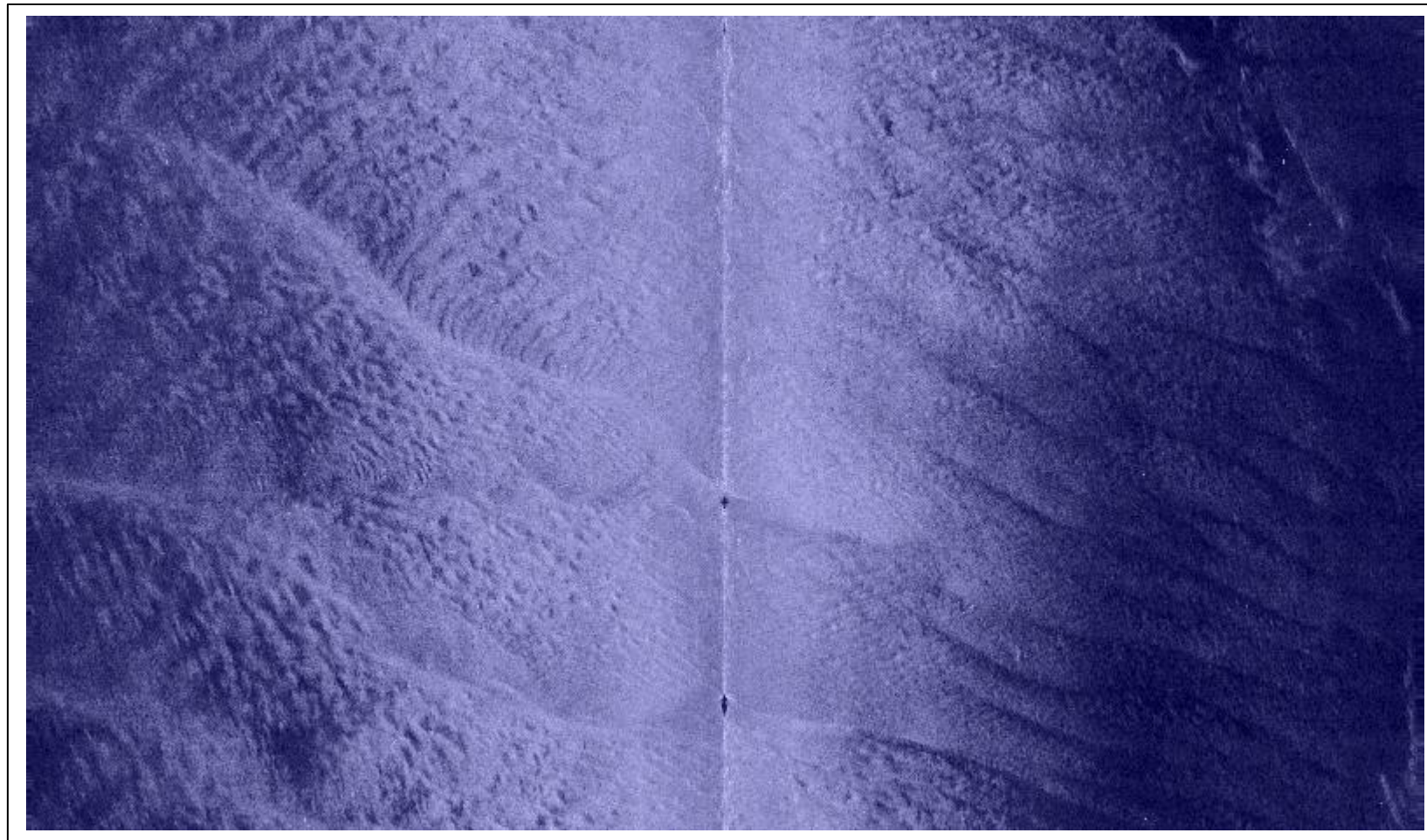
# Amplitude

The adjacent sonar image was captured in a river reach that appears to be composed entirely of sandy substrate. The ripple and dune patterning is characteristic of this substrate type in a lotic system (although sand does not always assume this appearance). Note the tonal change from left to right across this image. Toward the far right, the pixel tone darkens considerably, yet the rippling pattern indicative of sandy substrate remains. The reason for this difference in tone is likely a change in elevation (depth) across the image. It is likely that the left side of the image is relatively flat compared to the right side, which appears to be sloping away from the transducer (i.e., increasing in depth). We suspect that a trough, or deeper channel exists to the right hand side of the boat path. This image provides a good example of the effect of grazing angle on amplitude and image tone, and also how differences in tone can be interpreted to provide information on depth across the sonar swath.

\*When interpreting and discussing sonar imagery, it is important to emphasize that some degree of uncertainty often remains. The only way to confirm, for example, that a trough exists to the right of the boat in this image would be to obtain actual measurements of depth throughout this reach. In the paragraph above we use terms like "appears to be" and "likely" to indicate this uncertainty...but if we fail to use these terms in future discussions, know that some level of uncertainty exists whenever groundtruth data are incomplete or nonexistent.

# Amplitude

Bottom sloping away from the transducer returns a weaker signal due to oblique grazing angles



\*Note- The effect of bottom slope on grazing angle and signal return amplitude has particular relevance to the topic of automated image classification. As demonstrated above, pixel tone alone (i.e., the underlying numerical pixel values), cannot be used to correctly classify the substrate appearing in this image. 36

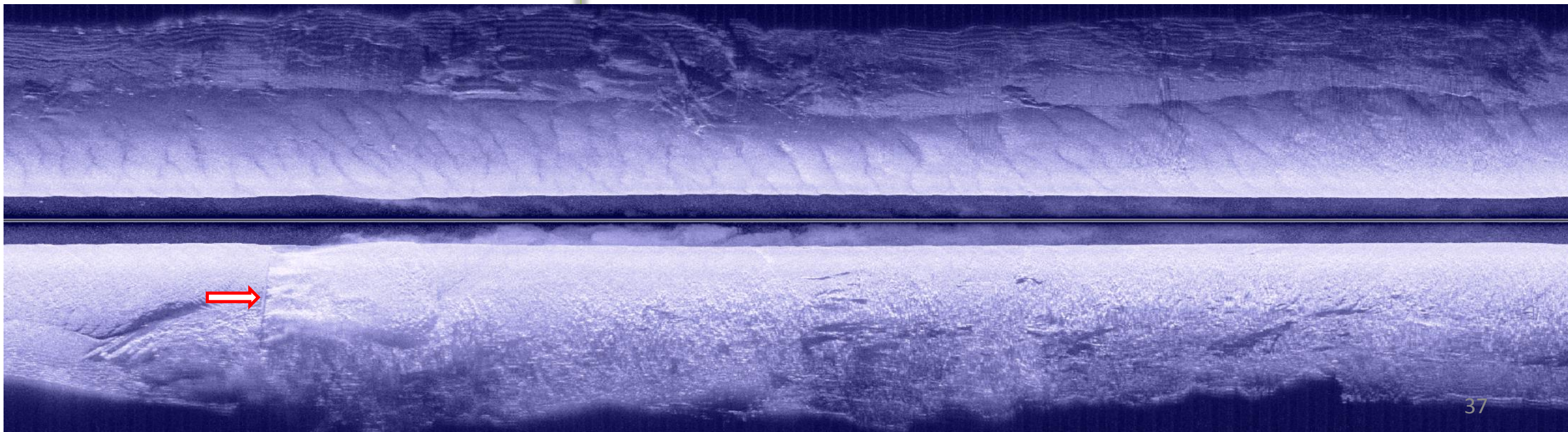


# Amplitude

We have discussed density and grazing angle influences on amplitude and image tone, yet several additional factors can also effect signal return strength, including water density, suspended particulates like leaves, entrained gasses, and water turbulence. The raw image mosaic below was captured on the Coosa River during a frigid February morning in North Georgia. In the lower left a submerged pipe extends perpendicular to the river channel. This pipe is discharging warm effluent from a riverside power plant. The density differences between the warm plume and cold river water is scattering the sonar signal, producing image distortion along the bottom half of the image. This distortion extends far downstream (compare both sides of image, above and below pipe).

# Amplitude

Amplitude can also be influenced by factors such as water density, enabling visualization of plumes of water of different temperature (for example), suspended particulates, entrained gasses, and turbulence (non-laminar flow)





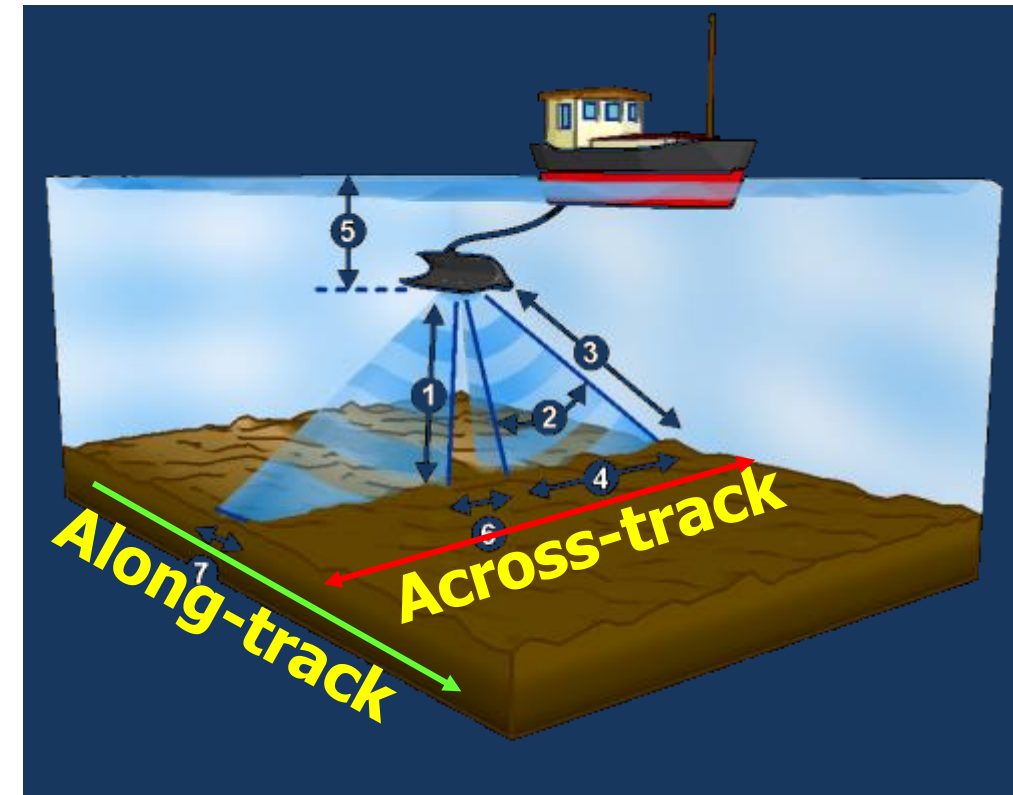
## Components of resolution

Now that we hit on the topic of image distortion, let's identify and discuss the two "principal components" of image resolution- along-track (or transverse) resolution and across-track resolution. Along-track resolution is associated with the dimension parallel to the boat path. Transverse resolution is the resolution associated with the dimension perpendicular to the boat path.

# Image Resolution / Quality

Two "principal components" of image resolution:

1. Along-track (Transverse) Resolution
2. Across-track Resolution



\*Image Source:  
<http://www.starfishsonar.com/technology/sidescan-sonar.htm>

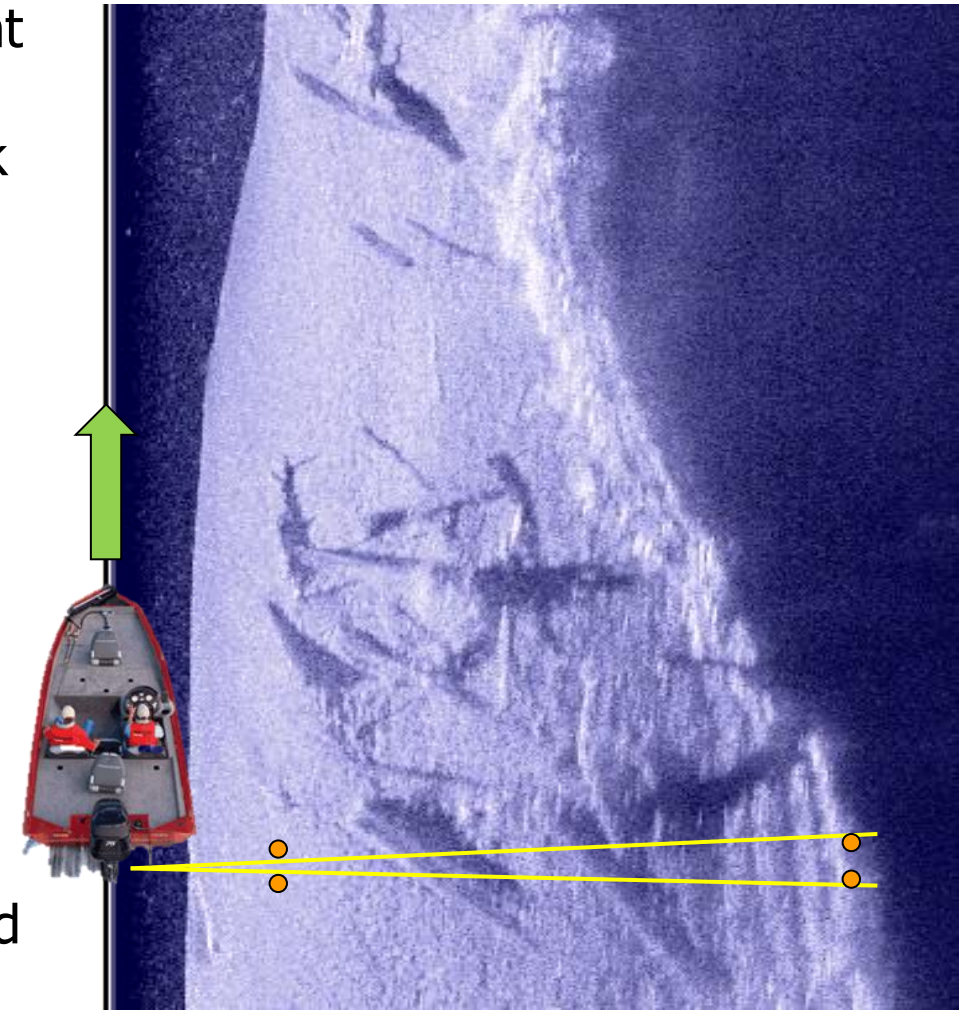
## Transverse resolution

Transverse resolution is the ability to discern two adjacent objects that are positioned parallel to, or along the path taken by the boat during the survey. Transverse resolution is also commonly referred to as target separation. This form of resolution is primarily a function of sonar beam (i.e., signal) width. As the sonar signal travels farther away from the transducer an interesting thing happens- its width increases. This phenomenon is called beam spreading or fanning. In practical terms this means that the sonar beam has a smaller footprint, or area of insonification, close to the boat, and a larger footprint at greater distances from the boat. The increasing size of the sonic footprint influences the ability to resolve two adjacent objects separated by a fixed distance in the resulting image.

In the example provided, two sets of imaginary objects (e.g., boulders) are positioned on the stream bottom- 1 set is close to the boat, and the other near the bank. The set of boulders near the boat will be resolved as two separate objects, however the distant set will not be resolved as separate objects in the resulting image due to the effect of beam spreading. In other words, transverse resolution declines with increasing perpendicular distance from the boat. The effect of declining transverse resolution is manifest in the form of image distortion, fuzziness, or blurriness in far-field portions of the sonar image. Note that in this image the near-bank features are less distinct in the lower half of the image than they appear in the upper half, which was closer to the transducer during the survey.

# 1) Along-Track / Transverse Resolution

- Transverse resolution: the ability to discern 2 adjacent objects positioned parallel to, or along, the boat track (also called target separation)
- Transverse resolution a primary function of sonar beam width
- Beam spreading/fanning occurs with increasing distance (range) from transducer, induces distortion in image as larger footprint is insonified by sonar beam
- Evident in far-field portions of image (fuzzy/blurry areas)



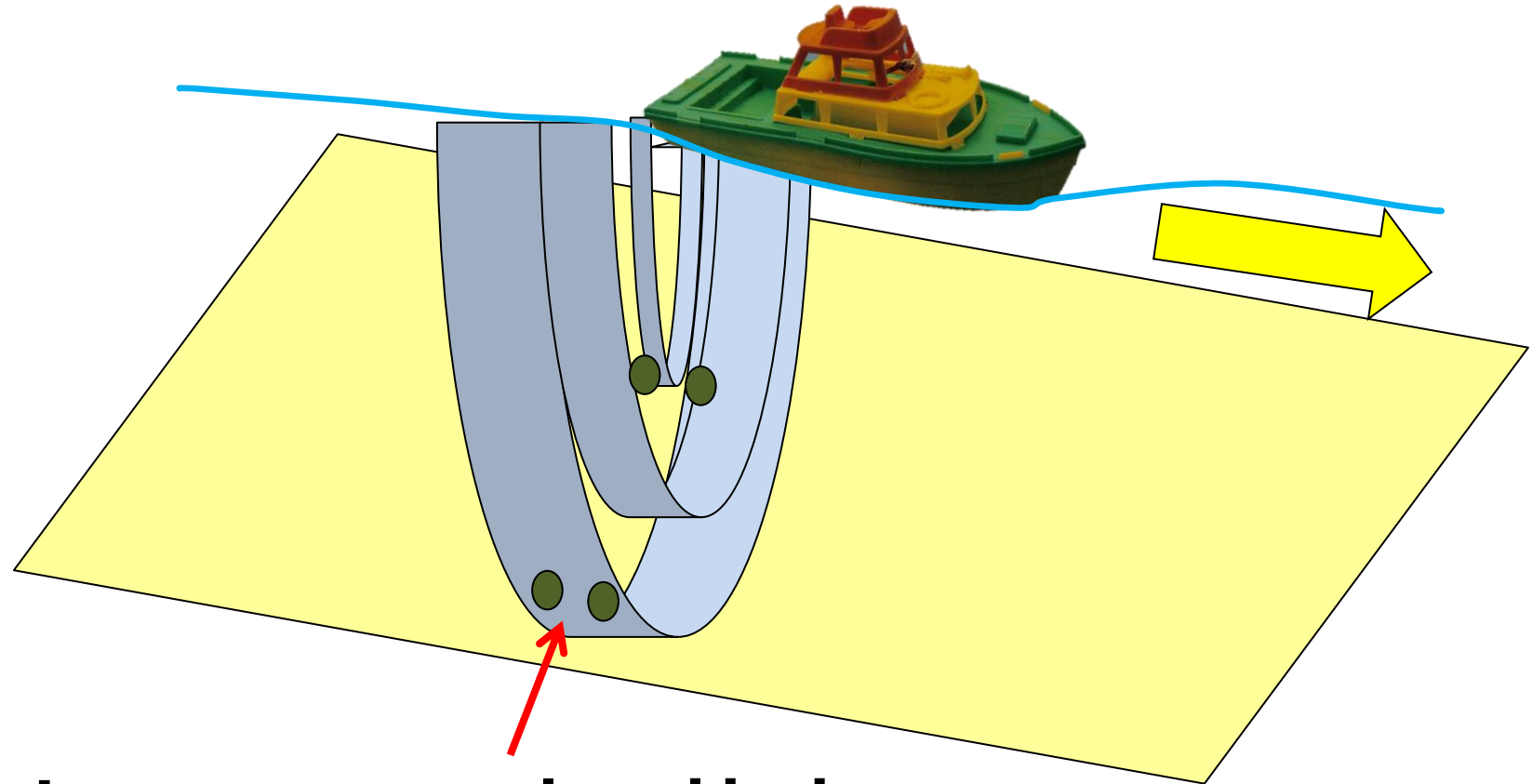
\*Figure adapted from Fish and Carr (1990)



## Transverse resolution

Here we attempt another illustration of the phenomenon of beam spreading and its effect on the ability to resolve objects at increasing distances from the boat.

# 1) Along-Track / Transverse Resolution



**Larger area enveloped by beam,  
larger “sonic footprint”**

## Range and resolution

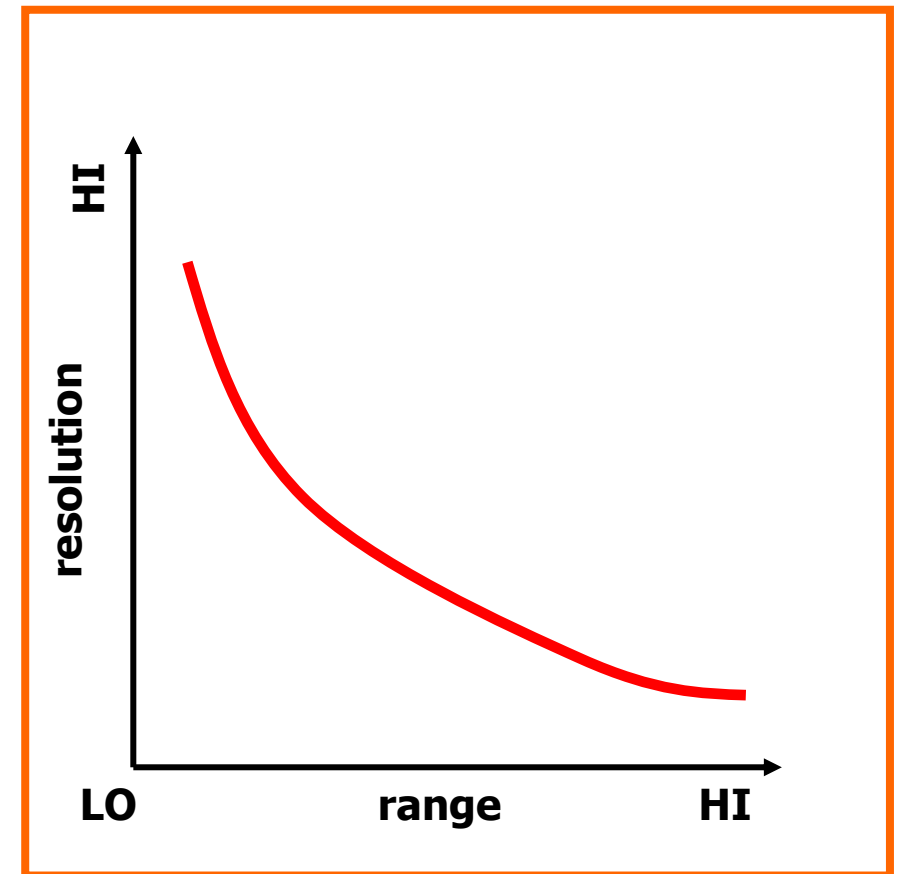
This brings our discussion to a fundamental relationship between sonar range and image resolution. Range is the widest (i.e., the farthest or deepest) distance that will be displayed in a sonar image. Range and image resolution are inversely proportional- as range increases, image quality declines in the far-field portions of the image.

Sonar range is a setting that can be manipulated by the sonar operator during a survey. Of all the settings that can be adjusted on the HSI system, the range has perhaps the most profound influence on image resolution and quality.

## Range vs. Resolution

**Range:** the deepest (widest) distance that will be displayed in an image

Range and resolution are inversely proportional, the higher the range the lower the image quality in far field portions.



\*Graph Adapted From: [http://www.tritech.co.uk/products/info/products-info-sidescan\\_sonars.htm](http://www.tritech.co.uk/products/info/products-info-sidescan_sonars.htm)



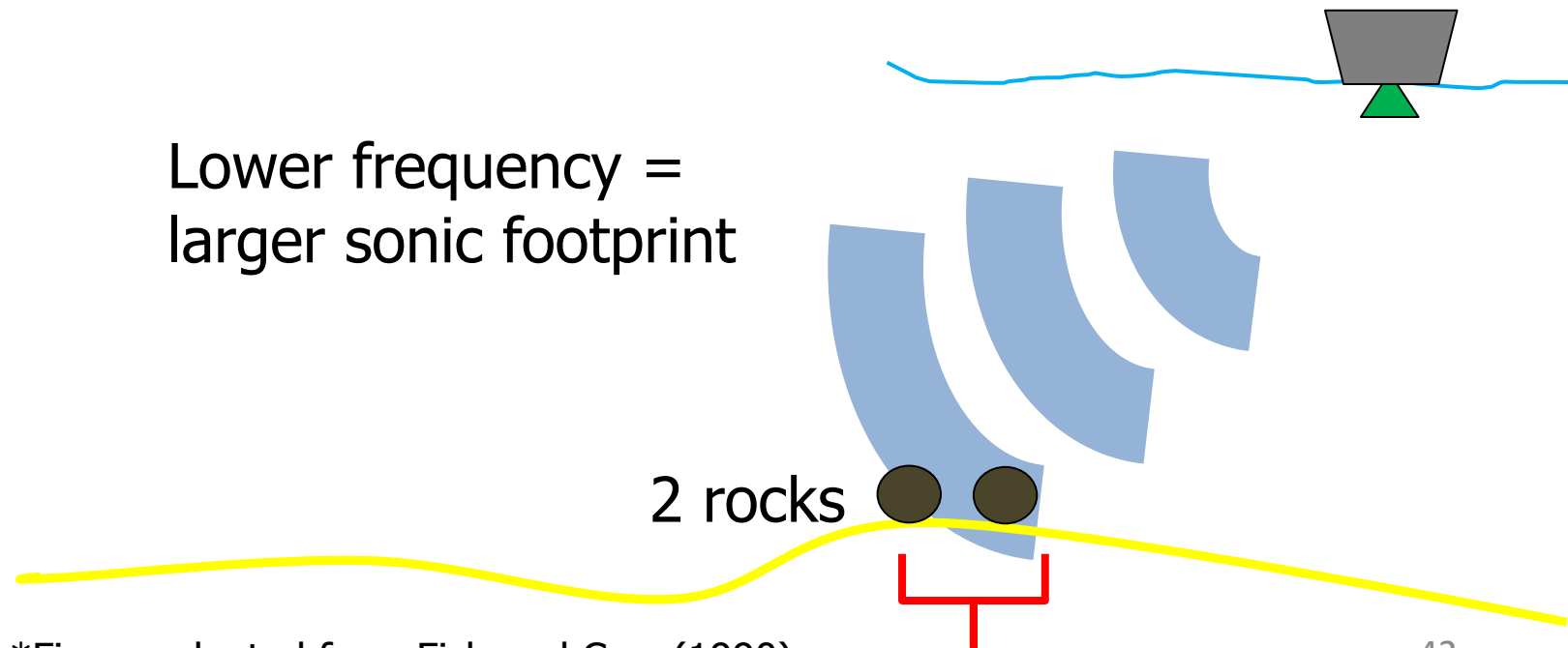
## Across-track resolution

Let's discuss the second principle component of image resolution. Across-track resolution is defined as the ability to discern two adjacent objects positioned perpendicular to, or across the path taken by the boat during the survey. Across-track resolution is a function of sonar frequency, or pulse length.

Lower sonar frequencies have a larger sonic footprint, reducing the resolving capability of the device. In this example, a low frequency pulse envelops both rocks simultaneously.

## 2) Across-track / Range Resolution

- Range resolution: the ability to discern 2 adjacent objects positioned perpendicular to, or across, the boat track
- Range resolution a function of pulse length (sonar frequency)



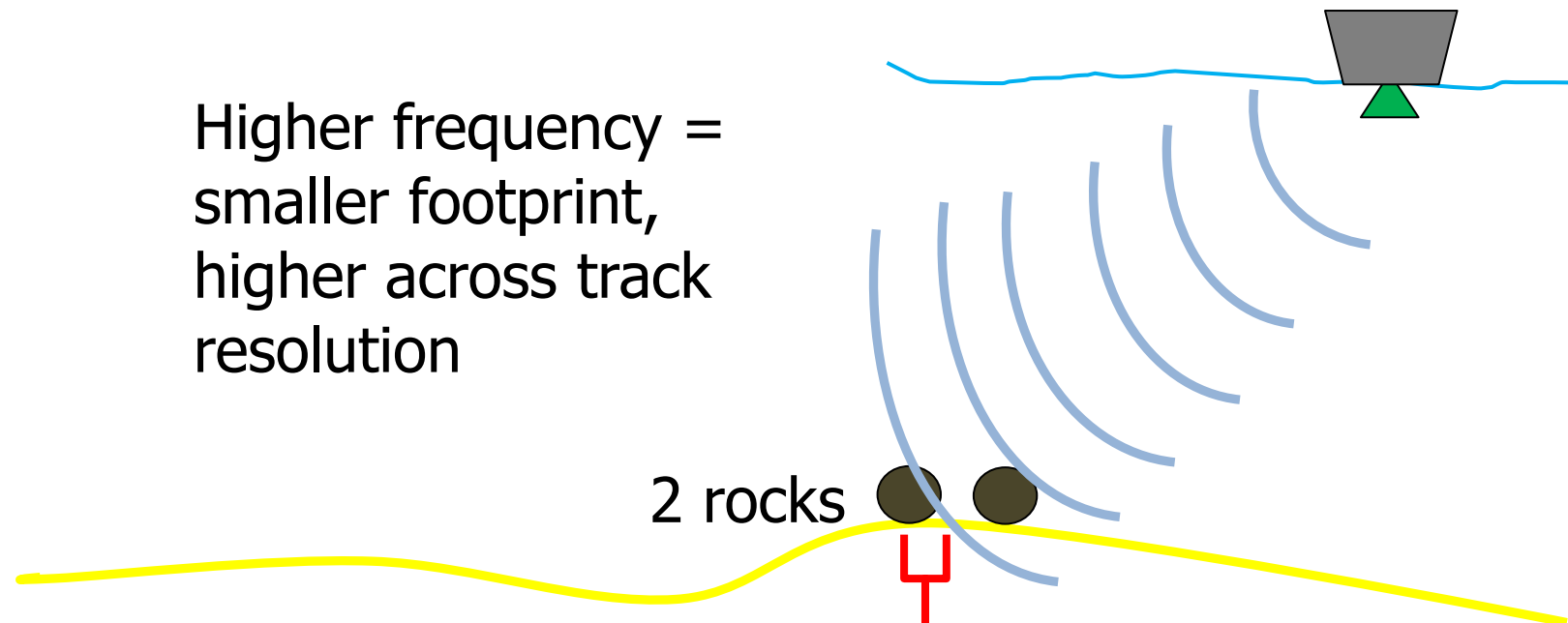
\*Figure adapted from Fish and Carr (1990)

## Across-track resolution

The use of higher sonar frequencies produces a smaller sonic footprint, thereby increasing the resolving power of the device. In this example, the higher frequency pulses encounter each rock separately, allowing both objects to be resolved as separate and distinct.

## 2) Across-track / Range Resolution

- Range resolution: the ability to discern 2 adjacent objects positioned perpendicular to, or across, the boat track
- Range resolution a function of pulse length (sonar frequency)



\*Figure adapted from Fish and Carr (1990)



## Frequency and resolution

Thus, a fundamental relationship also exists between sonar frequency and image resolution. Frequency is a measure of the number of sound wave cycles per second. Sonar frequency and image resolution are directly proportional. Higher frequencies produce higher image resolution.

Various side scan sonar systems can operate in the range of 25 to 1600 kilohertz (kHz). The Humminbird® Side Imaging system operates at two very high frequency settings, either 455 kHz or 800 kHz.

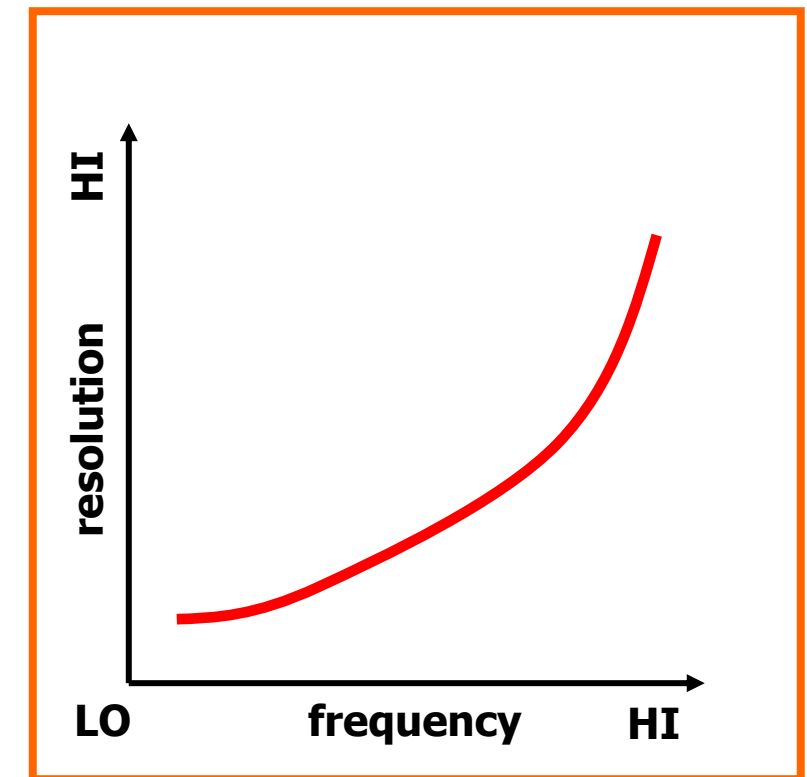
Given the relationship between frequency and resolution wouldn't it make sense to choose the highest available operating frequency? The answer to this question depends on the objectives of the sonar survey mission. In fact, there is an important trade off associated with use of higher sonar frequencies...

## Frequency vs. Resolution

**Frequency:** a measure of the number of sound wave cycles per second (kHz).

Frequency and resolution are directly proportional- the higher the frequency the higher the resolution.

So, shouldn't we use the highest frequency available?



\*Graph Adapted From: [http://www.tritech.co.uk/products/info/products-info-sidescan\\_sonars.htm](http://www.tritech.co.uk/products/info/products-info-sidescan_sonars.htm)

## Frequency and Range

Higher frequency signals attenuate faster than lower frequencies as they are absorbed and scattered more easily by elements of the aquatic medium. Thus, an inverse relationship exists between sonar frequency and range. Lower frequencies have a higher maximum operating range than higher frequencies.

The use of higher frequency may improve the ability to resolve smaller objects such as small diameter substrate materials, but the signal may be ineffective at reaching and imaging distant portions of the channel. To reiterate, higher frequencies will have a lower effective operational range than lower frequencies.

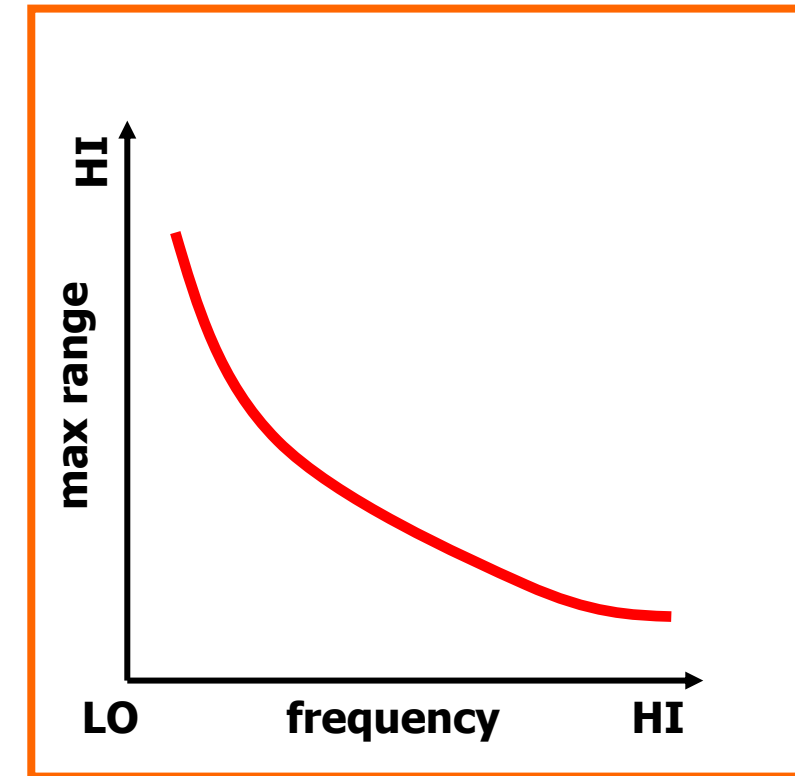
This trade-off between frequency and range is often exploited during search and recovery operations. When vast areas of open water must be scanned in search of a sunken vessel, a lower sonar frequency will be used at high range, thereby covering a large swath in each pass. The sonar operator will examine the record for anomalous objects, anything that appears out of the ordinary. The low frequency may not be sufficient to produce a detailed image of the sunken vessel, but may still reveal the object as something different from the surrounding matrix. When anomalous objects are encountered, return passes near the object can be made using higher frequency to produce a more detailed view of the object in question.

## Frequency vs. Range

Higher frequencies attenuate faster (are absorbed and scattered more easily) than low frequencies.

Thus, frequency and range are inversely proportional, the higher the frequency the lower the maximum range.

Therefore, there are trade-offs between frequency, range, and resolution.



\*Graph Adapted From: [http://www.tritech.co.uk/products/info/products-info-sidescan\\_sonars.htm](http://www.tritech.co.uk/products/info/products-info-sidescan_sonars.htm)



# HSI Frequency

The contemporary Humminbird® Side Imaging system has two operating frequencies- 455 and 800 kHz. The 455 kHz frequency has been used exclusively during our work, and nearly all of the images presented in this workbook were captured at this frequency. One reason for our reliance on 455 kHz is that the unit we purchased in 2006 (the original 981c SI) was incapable of running 800 kHz. Another important reason for our use of 455 kHz is the fact that this frequency produces high quality imagery with a functional range of up to ~150 feet per side. The ability to image whole river channels ( $\leq 300$  ft wide) in one survey pass has been a benefit to many of our mapping projects. The stated pixel resolution (i.e., the target separation) of imagery produced using 455 kHz is 6 cm.

Recently we have acquired newer HSI systems capable of operating at the higher 800 kHz frequency. Our experience is thus somewhat limited in terms of evaluating the use of this frequency in different settings and conditions. A diagram in the HSI manual (shown right) appears to indicate that 800 kHz is incapable of imaging 180 degrees across the channel, reaching both banks. We can neither confirm nor deny this claim at this time.

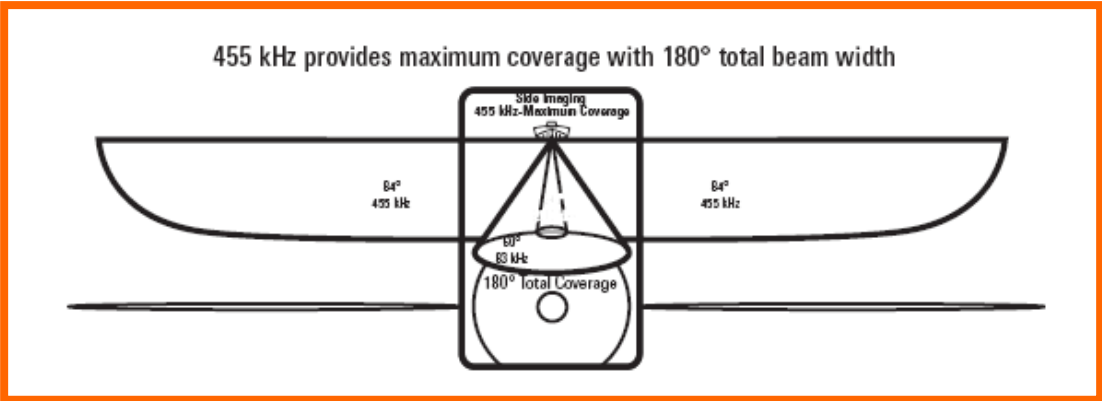
The stated pixel resolution of imagery produced using 800 kHz is 2 cm. The use of 800 kHz may prove to be useful for improving discrimination among fine textured substrate classes at short range- a point we will return to later in our discussion.

# HSI Operating Frequencies & Range

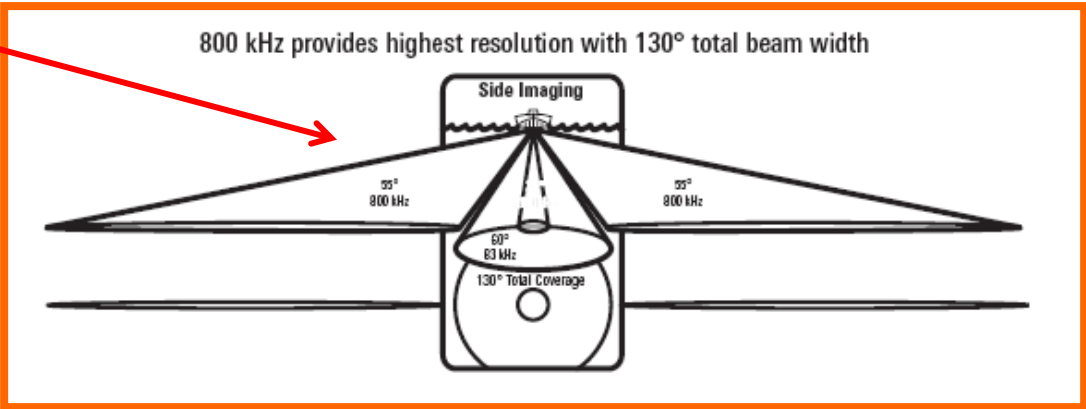
## 2 Operating frequencies to choose from- 455 or 800 kHz

But...does 800 kHz cover the entire water column??

800 kHz may prove useful for discriminating fine sediment classes at short range.



**5** pixels per foot = ~ 6 cm resolution or target separation at <100' range setting



**15** pixels per foot= ~ 2 cm resolution or target separation

\*Image Source: Humminbird 997 SI Manual



## 455 vs 800 kHz

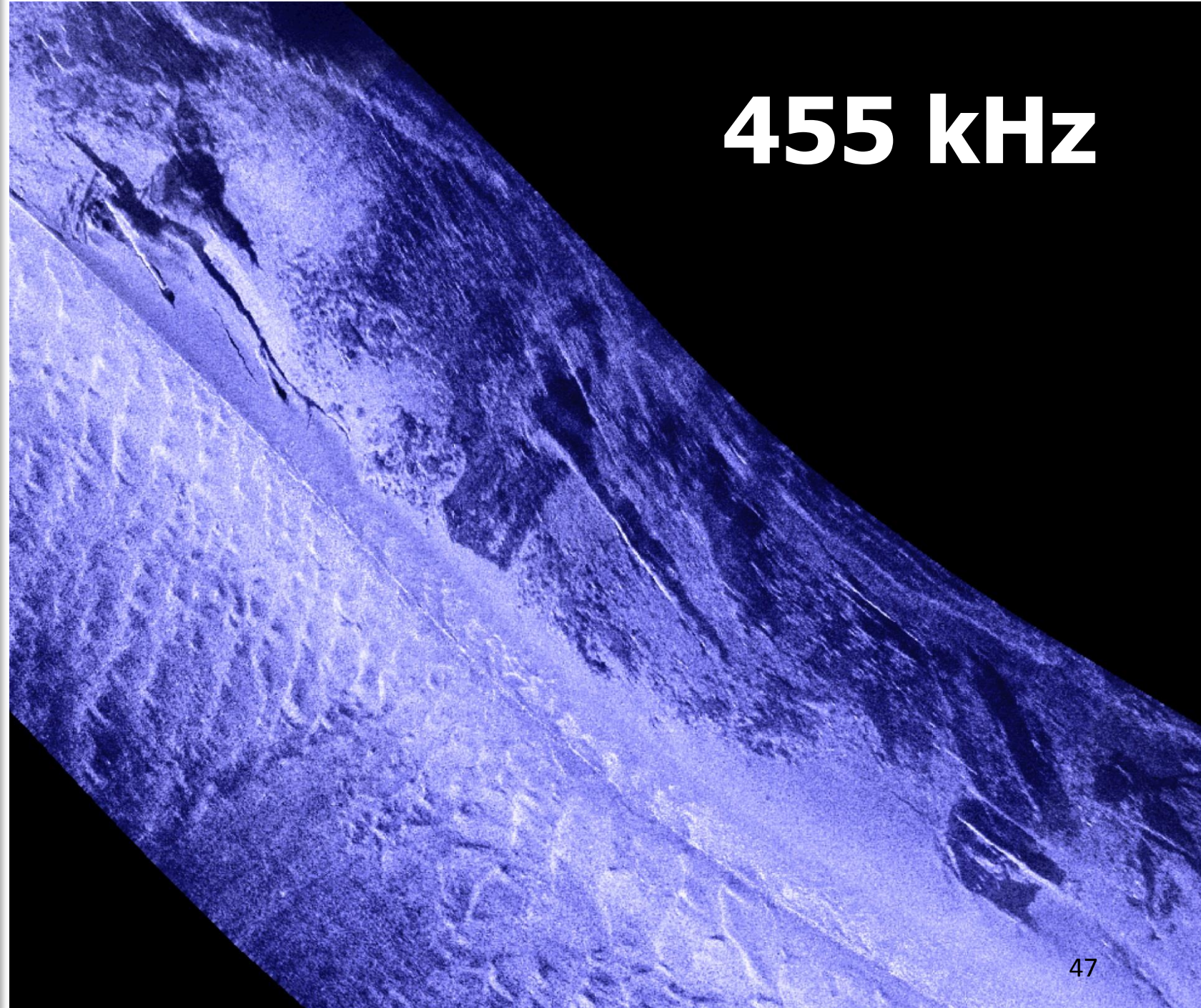
Here is a reach of the Altamaha River in Georgia that was scanned using both frequencies for test purposes- the results provide some illustration of the effect of operating frequency on image resolution.

When comparing it is easiest to select a discrete area of the image, and flip between the images to examine differences. Although no two sonar images of the same area can ever look exactly alike, even when captured at the same frequency, it is usually possible to reference common areas in both images. Let's look, for example, at the logs that appear along the bank of the river. I can find most of the same logs in both images. The rippled sand forms in mid-channel are slightly more defined, and have sharper edges in the 800 kHz mosaic (next page). Take a close look at the rock/rubble piles that are scattered along the river margin. These rock piles are somewhat more defined in the 800 kHz mosaic.

Note the difference in mosaic width- this is related to the use of shorter ranges settings during the 800 kHz pass. Note, too, that the tone begins to darken rather noticeably toward the outer limits of the sonar range (near the image edges) in the 800 kHz mosaic relative to the 455 kHz mosaic. This darkening is due to signal attenuation.

# Comparing Frequencies

## 455 kHz

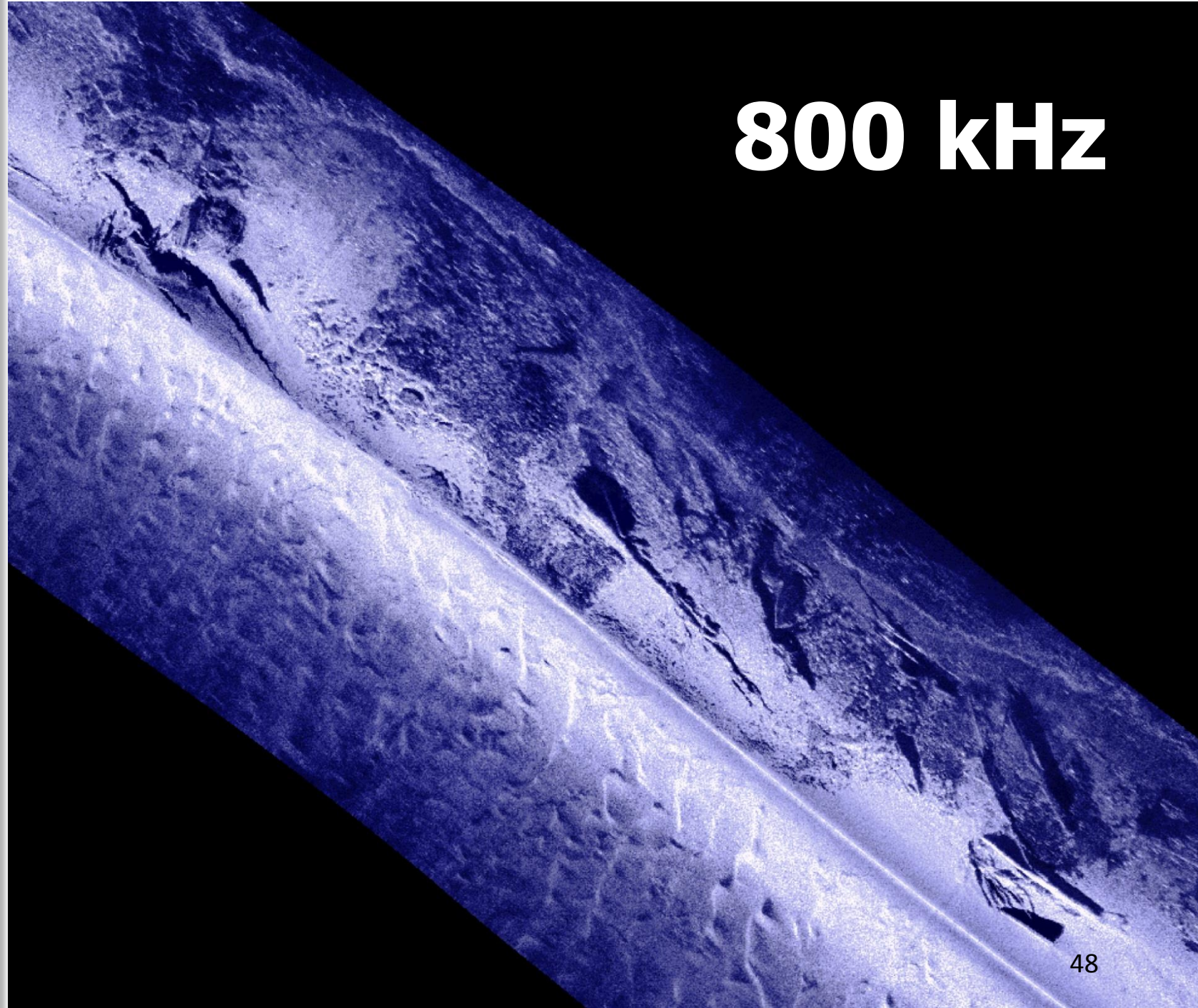




455 vs 800 kHz

# Comparing Frequencies

**800 kHz**



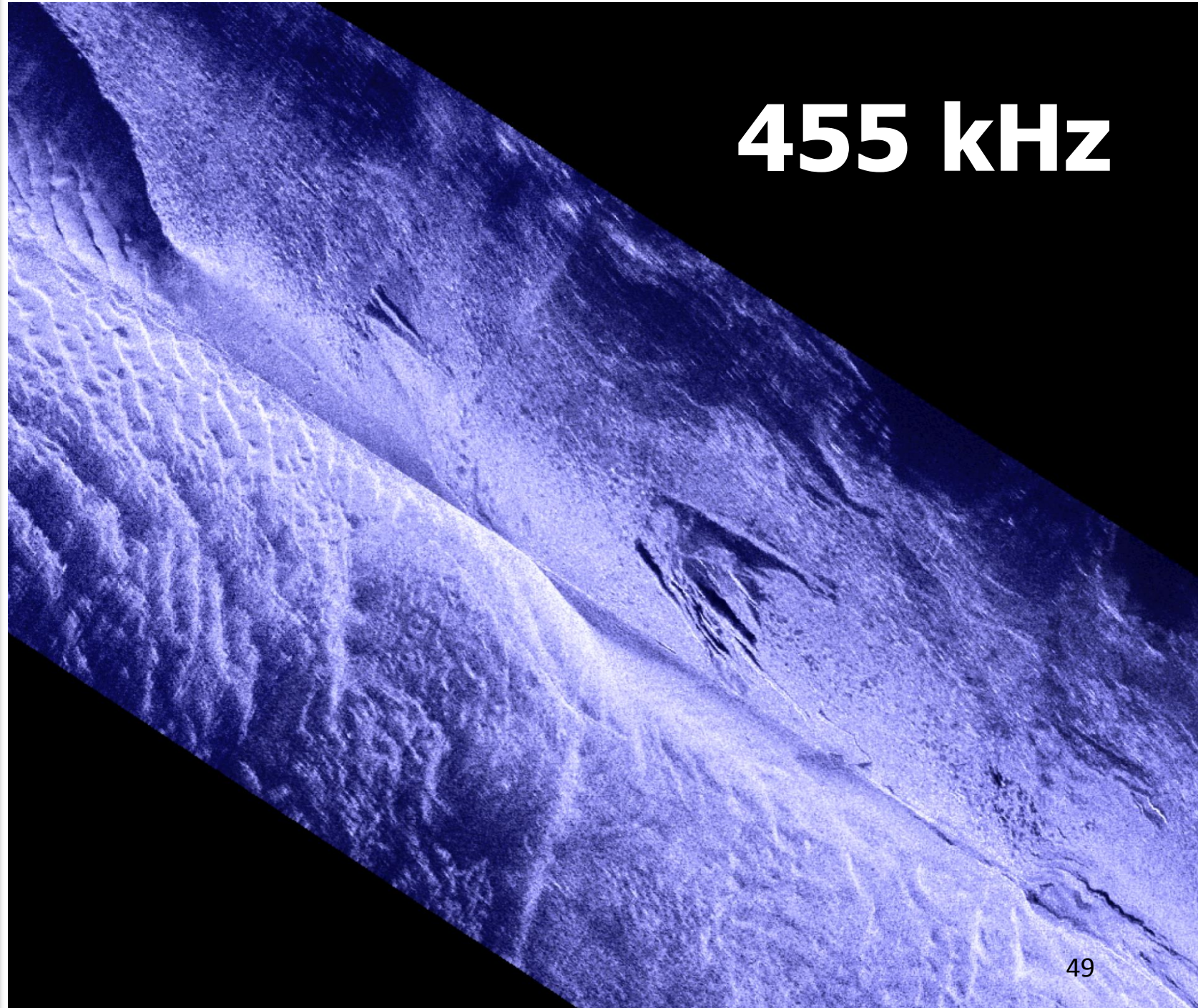


## 455 vs 800 kHz

Here we display another reach of the Altamaha River for purposes of comparing sonar frequencies. In this image a nice cache of logs exists in the middle of the image. An expansive area of fine rocky substrate (likely cobble-sized material with some gravels) is distributed along the upper portion of the image. A vast area of migrating sand dunes and ripples occupies the lower half of the image. To a trained eye, these features are rather obvious in the 455 kHz mosaic.

# Comparing Frequencies

**455 kHz**





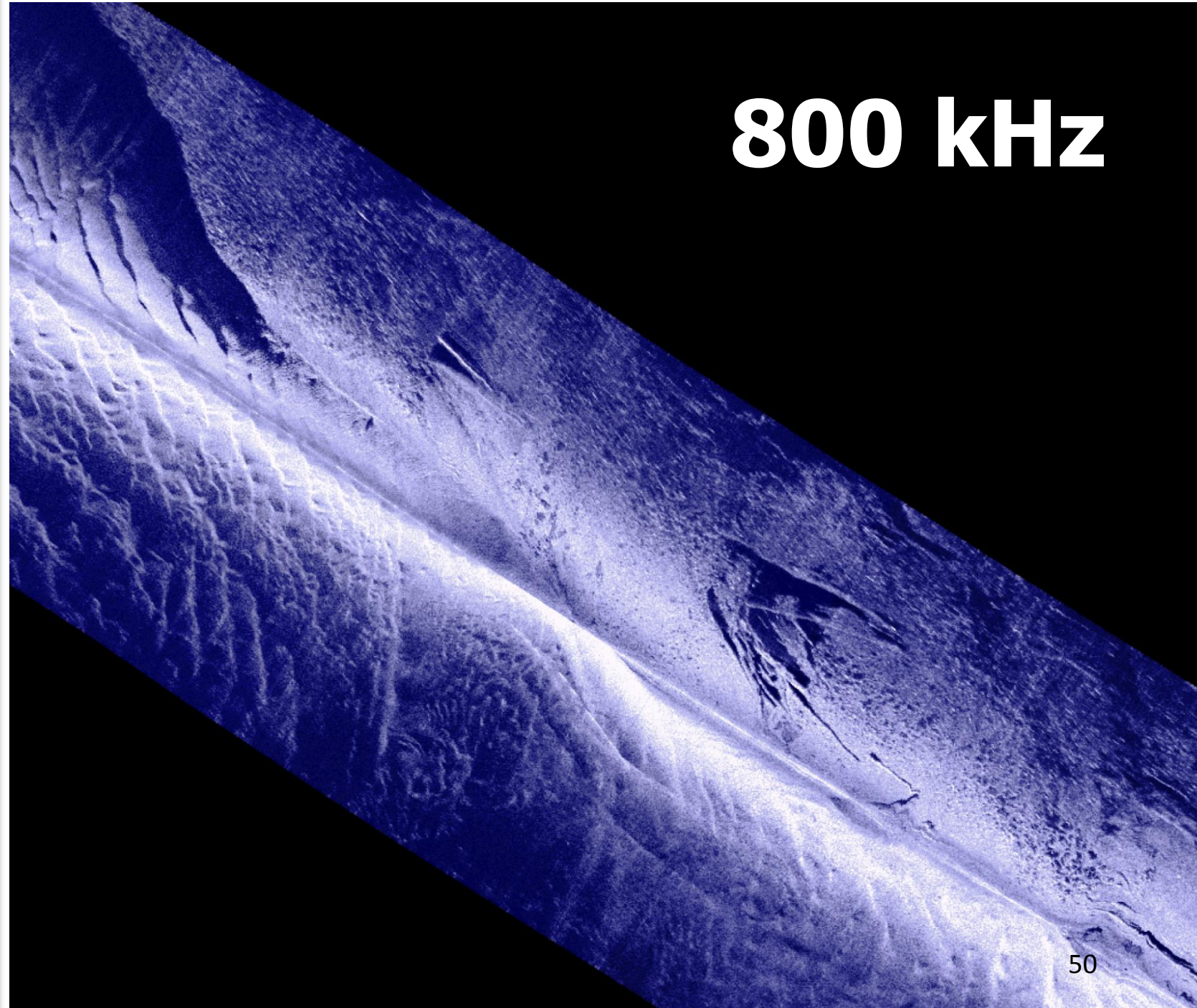
## Which frequency to use?

The use of 800 kHz sharpens up the definition on some of the notable features, like the log cache, the cobble deposits, and the sand ripples. Whether the improvement in resolution is worth the expensive of the reduction in range is debatable. On other occasions we have observed a strong effect of water column turbulence and debris on the imaging performance of 800 kHz. The examples provided here represent results obtained during favorable imaging conditions.

We encourage you to experiment with both frequencies during the survey planning phase, and critically evaluate performance with respect to meeting the specific needs and objectives of your sonar survey project.

## Comparing Frequencies

**800 kHz**



## Saltwater applications

By this point in the program someone is usually interested to know if the Humminbird® system can operate in saltwater/marine environments. The short answer is yes, and there is a control head setting for specifying use in either fresh or saltwater. We do not know what effect this setting has on the performance of the system, although we have scanned in marine environments using the saltwater setting and the imagery was comparable. The following session of the workshop will address many more questions relating to where and when to expect the system to perform optimally.

## Does it work in saltwater?

- Yes- there is a water type (fresh or salt) setting
- Sound attenuates faster in saltwater than in fresh (absorption by solutes)



For example, at 500 kHz,  
usable range reduced  
~25% in saltwater



# 900 or 1100 series?

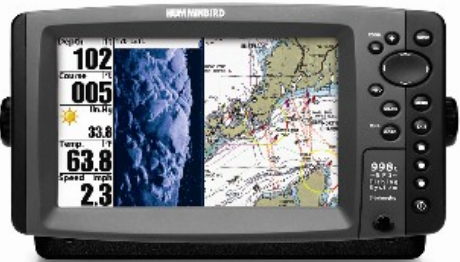
In the short time that elapses between workshops, the Humminbird® company usually releases a new model of the HSI system and discontinues older models. The purpose of doing so is unclear to us, as it seems that all of the Side Imaging systems offer the same basic functions and performance in terms of image production and quality- the details that matter most when preparing sonar-based habitat maps. All contemporary units can run both 455 and 800 kHz. (As mentioned earlier, the original 981c SI did not offer 800 kHz as an upper limit frequency).

A major difference between the 900 and 1100 series is the size of the control head screen. Although physically larger, the number of pixels in the x-dimension is the same in both models- only the pixels themselves are larger on the screen in the 1100 series. Image quality is generally improved by adding more pixels to a display (i.e., more megapixels in your digital camera photographs), yet we can expect only moderate improvements related to pixel count in the 1100 series. This improvement comes from the fact that the alignment of the information bar was moved from the far left of the display in the 900 series to the bottom of the display in the 1100 series, thereby freeing up some x-dimension pixels for image production. The screen scrolls top to bottom (north to south) thus it is the x-dimension pixel number that is of any relevance to image quality. The expected, or theoretical improvement in image quality is not readily apparent to us at this point in time.

# Which HSI system to buy?

981c, 997c, 1197c (discontinued)

- 998c SI Combo or
- 1198c SI Combo?



## 998c SI Combo 900 Series

Model: 998c SI Combo

**NEW IN 2010**  
**Side Imaging Sonar/External GPS Combo**  
The 998c SI Combo features a brilliant color, wide-screen 480V x 800H 8" display, Side Imaging and DualBeam PLUS sonar with up to 8000 Watts PTP\* power output, GPS Chartplotting with built-in ContourXD mapping, and advanced Fishing System capabilities. In addition, it includes dual card slots for maps and saving waypoints. Includes unit cover. Maximize your angling experience with the Humminbird 998c SI Combo fishfinder GPS system.

\*To obtain 8000 watts PTP requires the use of the optional 1kW (8000watt) transducer.  
Watch Hank Parker demonstrate Side Imaging technology on the Humminbird 997c.



## 1198c SI Combo 1100 Series

**Side Imaging Sonar/External GPS Combo**  
The 1198c SI Combo features a huge 10.4" display with LED backlight, Side Imaging and DualBeam PLUS sonar with up to 8000 Watts PTP\* power output, GPS Chartplotting with built-in ContourXD maps, and advanced Fishing System capabilities. Includes unit cover and in-dash mounting kit. Maximize your angling experience with the Humminbird 1198c SI Combo fishfinder system.

\*To obtain 8000 watts PTP requires the use of the optional 1kW (8000watt) transducer.  
Watch Hank Parker demonstrate Side Imaging technology on the Humminbird 997c.

Watch Rick Murphy use his Humminbird 997c on saltwater.

**MSRP \$2,799.99** [Share](#) [Like](#)  
**Add to Cart**

## Additional references

The body of literature that exists on the topic of side scan sonar is not very extensive, but we have found the two Fish and Carr books to be very interesting and insightful. Fish and Carr (1990) contains a chapter on theory of operation that we found to be very helpful in preparing portions of this session. On the other hand there are several informal sources for information on the Humminbird® system available online via the two forums listed here. One site is officially endorsed by Humminbird® and the other is an unofficial site. Both are frequented by passionate, HSI devotees who post on a variety of topics. These forums contain lengthy discussions and users freely offer advice and recommendations. Representatives of the Humminbird® company also post responses to user inquiries at these sites.

This concludes Session I-Part A of the workshop.

## For More Information

- [www.sideimagingsoft.com](http://www.sideimagingsoft.com)
- <http://www.xumba.scholleco.com/>



- Fish, J. P. and H. A. Carr. 1990. Sound Underwater Images- A guide to the generation and interpretation of side scan sonar data. Lower Cape Publishing, Orleans, MA.
- Fish, J. P. and H. A. Carr. 2001. Sound Reflections- Advanced applications of side scan sonar. Lower Cape Publishing, Orleans, MA.
- Fisheries Acoustics, Theory and Practice. 2005. J. Simmonds and D. MacLennan. Blackwell Publishing